University of Pittsburgh

Algorithms and Data Structures 2
CS 1501

Spring 2023

Sherif Khattab

ksm73@pitt.edu

(Slides are adapted from Dr. Ramirez's and Dr. Farnan's CS1501 slides.)

Announcements

- Upcoming Deadlines
  - Homework 6: this Friday @ 11:59 pm
  - Lab 5: Tuesday 2/28 @ 11:59 pm
  - Assignment 2: Friday 3/17 @ 11:59 pm
    - Support video and slides on Canvas
- Midterm Exam on Wednesday 3/1
    - in-person, closed-book
    - Study guide and old exams on Canvas
    - Practice questions on GradeScope (with answers)
- Lost points because autograder or simple mistake?
  - please reach out to Grader TA over Piazza
- Navigating the Panopto Videos
  - Video contents
  - Search in captions

Previous lecture

- Huffman Compression

This Lecture

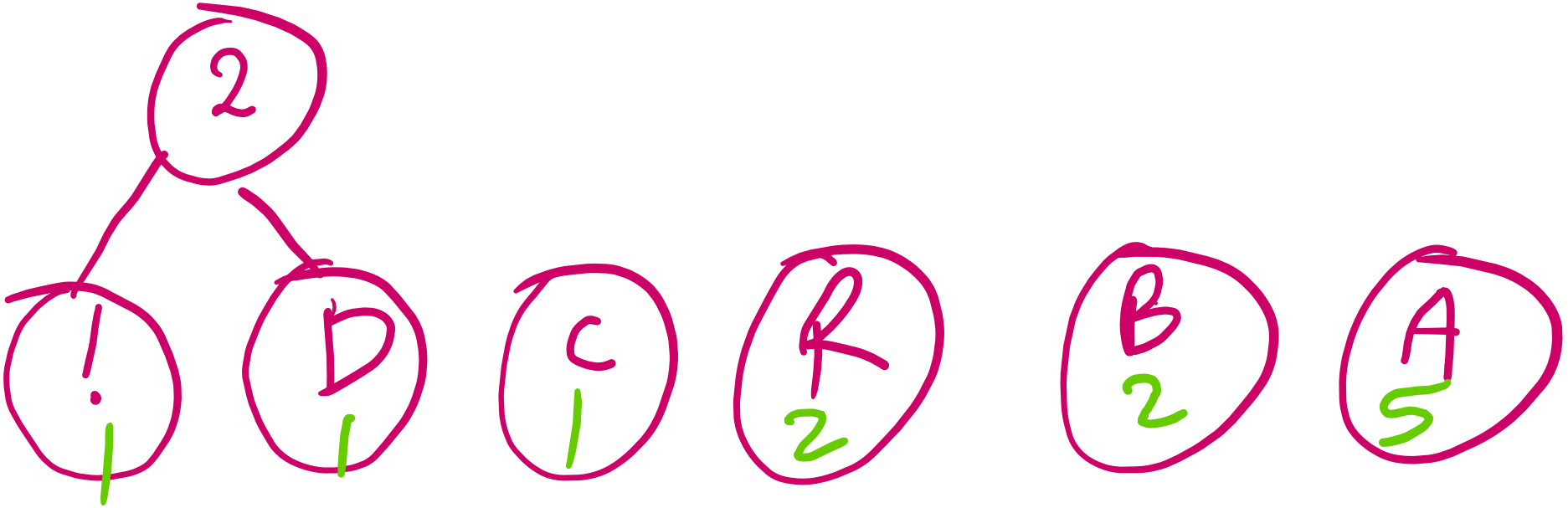
- Huffman Compression
- Run-length Encoding
- LZW

Huffman Compression Example

- Build a tree for “ABRACADABRA!”
- file size: *n* = *12*
- no. of unique characters: *K* = *6*

Example

- Build a tree for “ABRACADABRA!”



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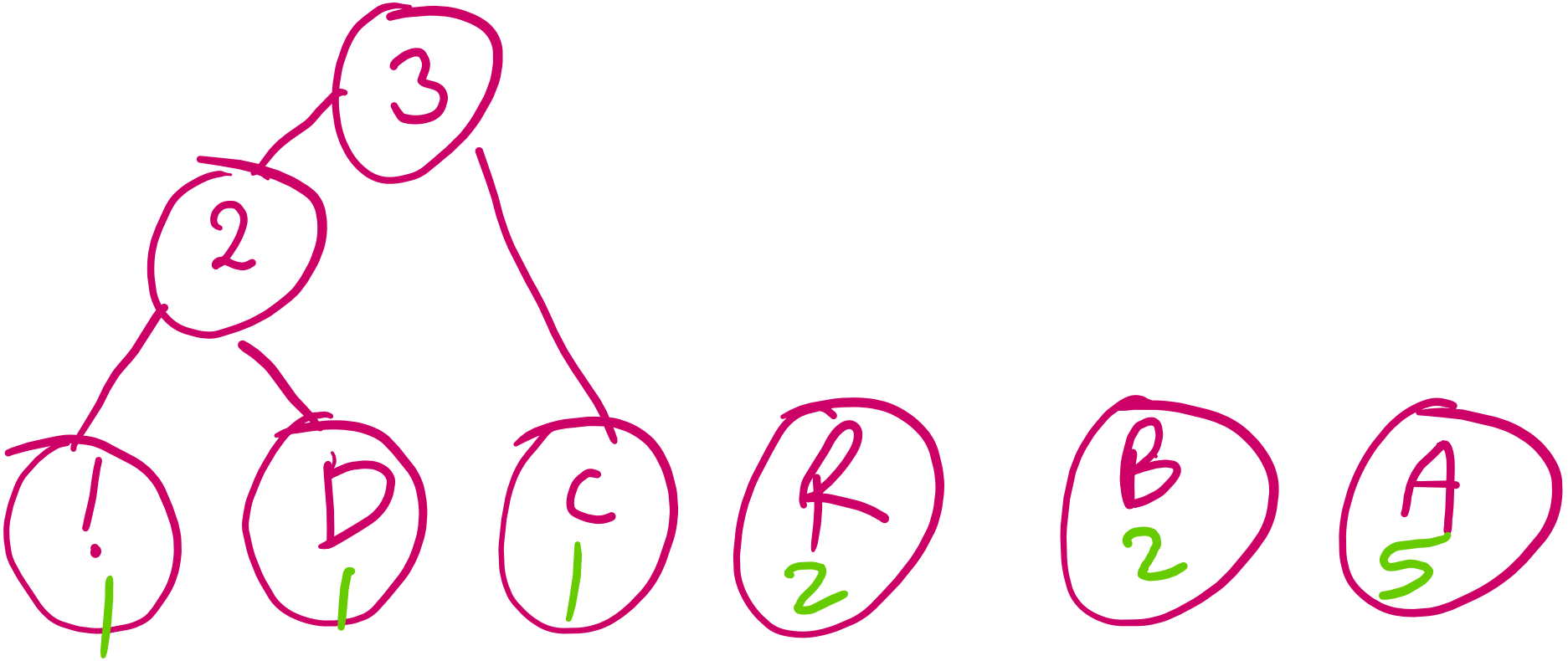

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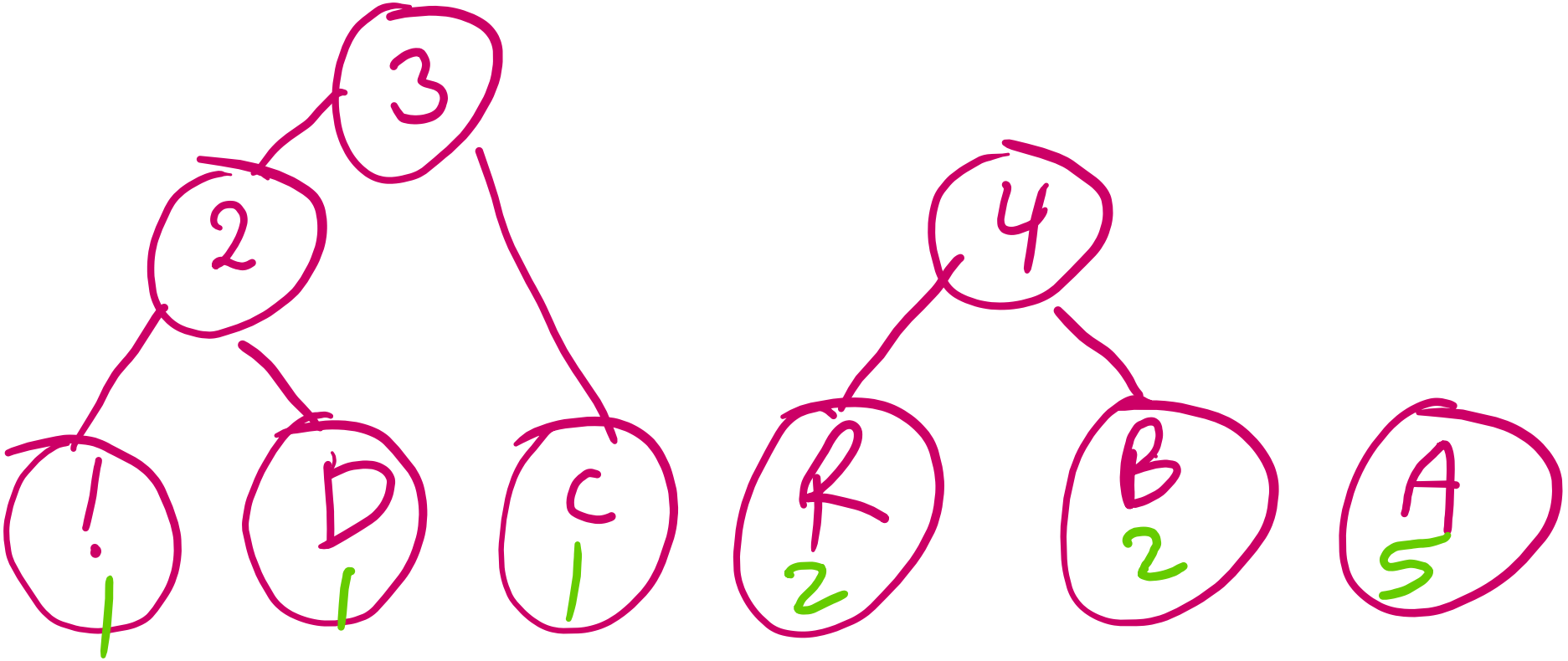

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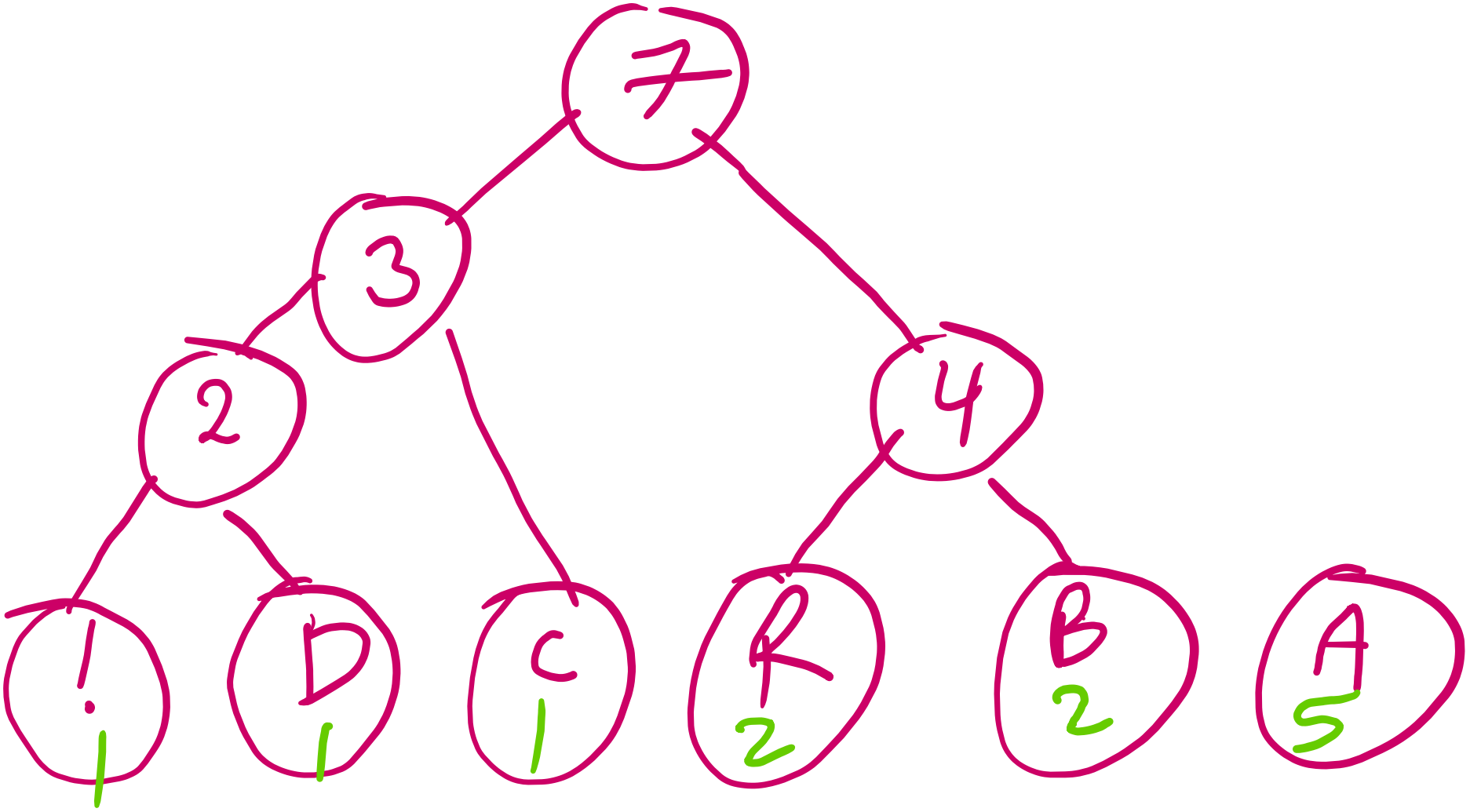

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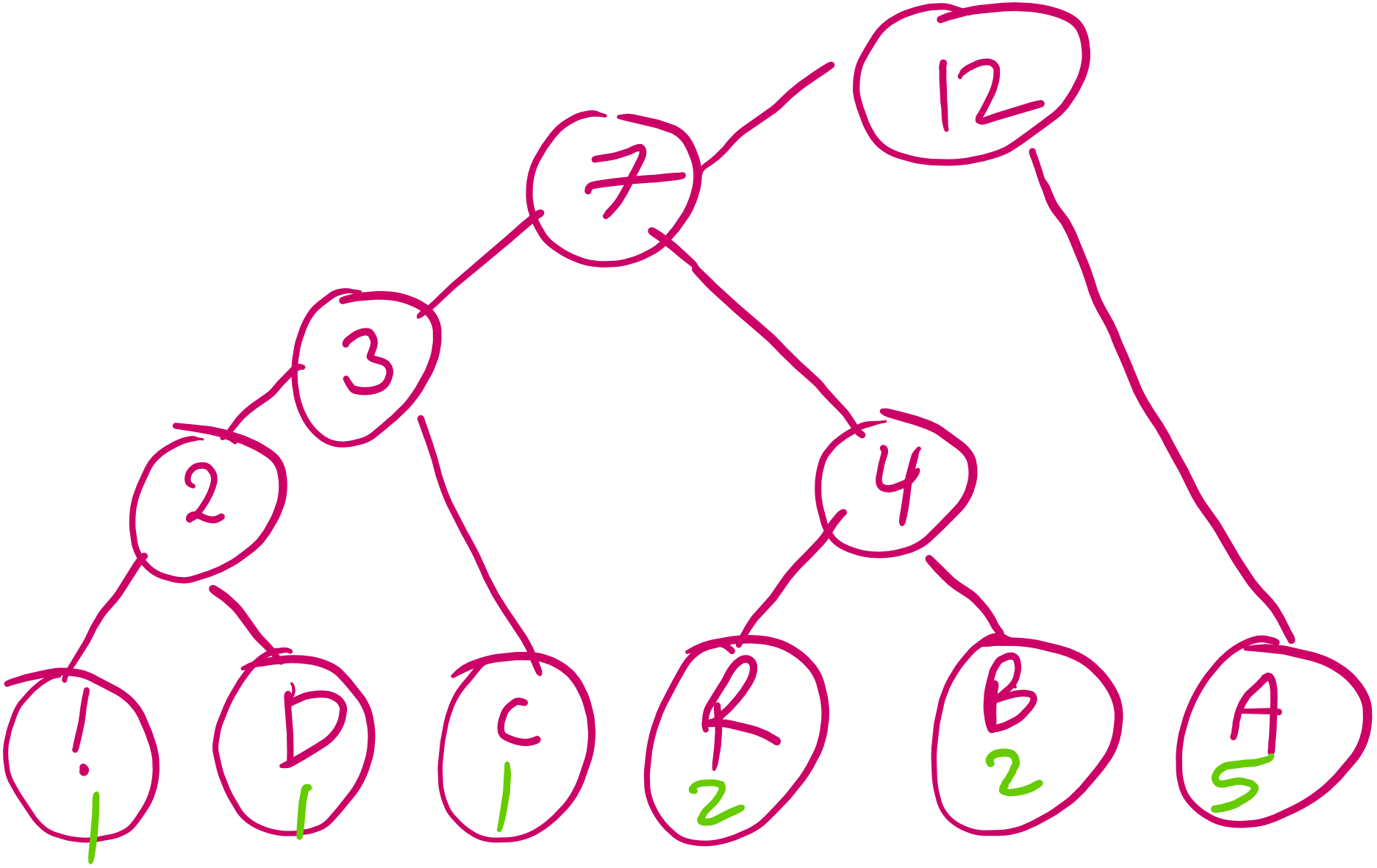

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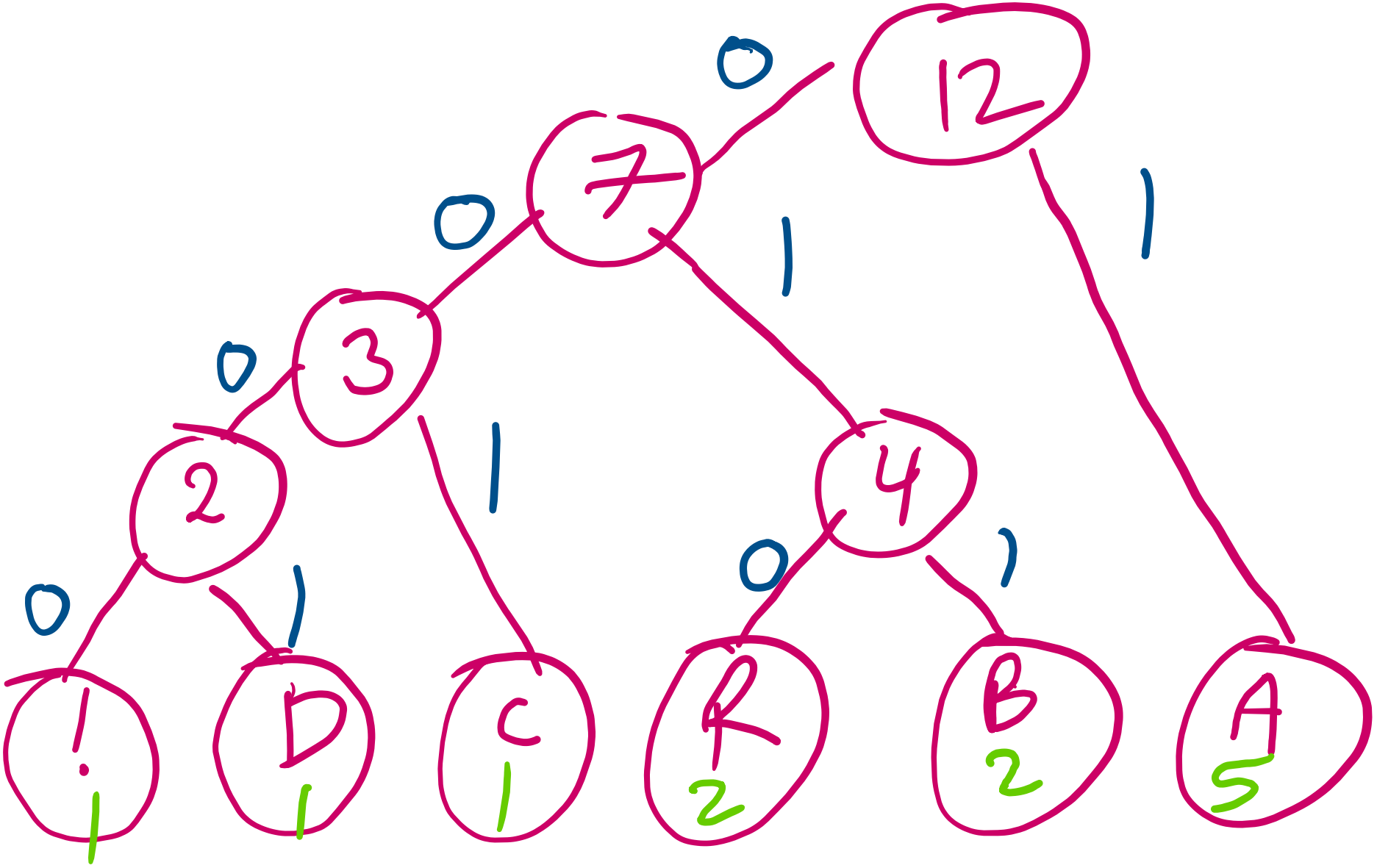

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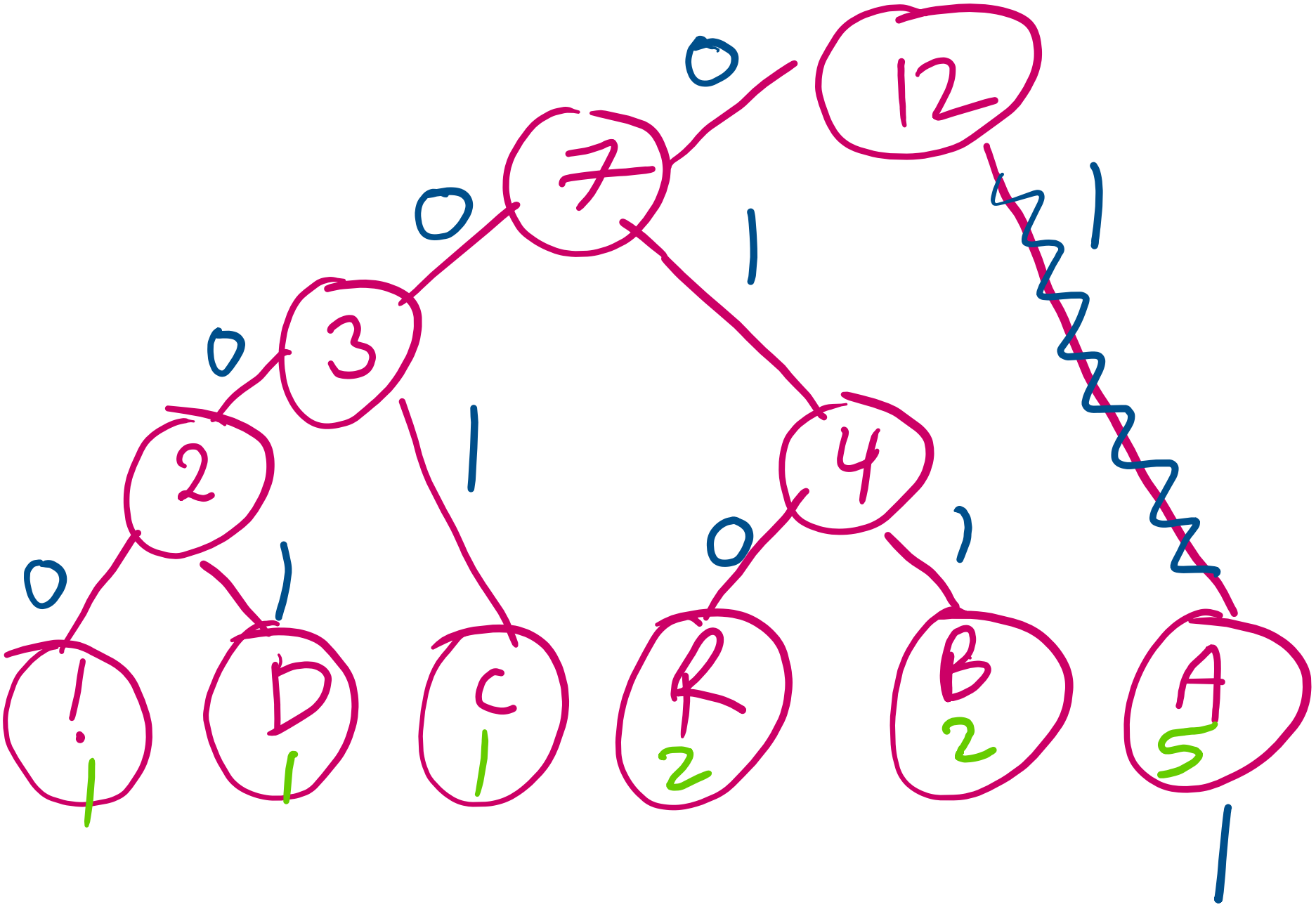

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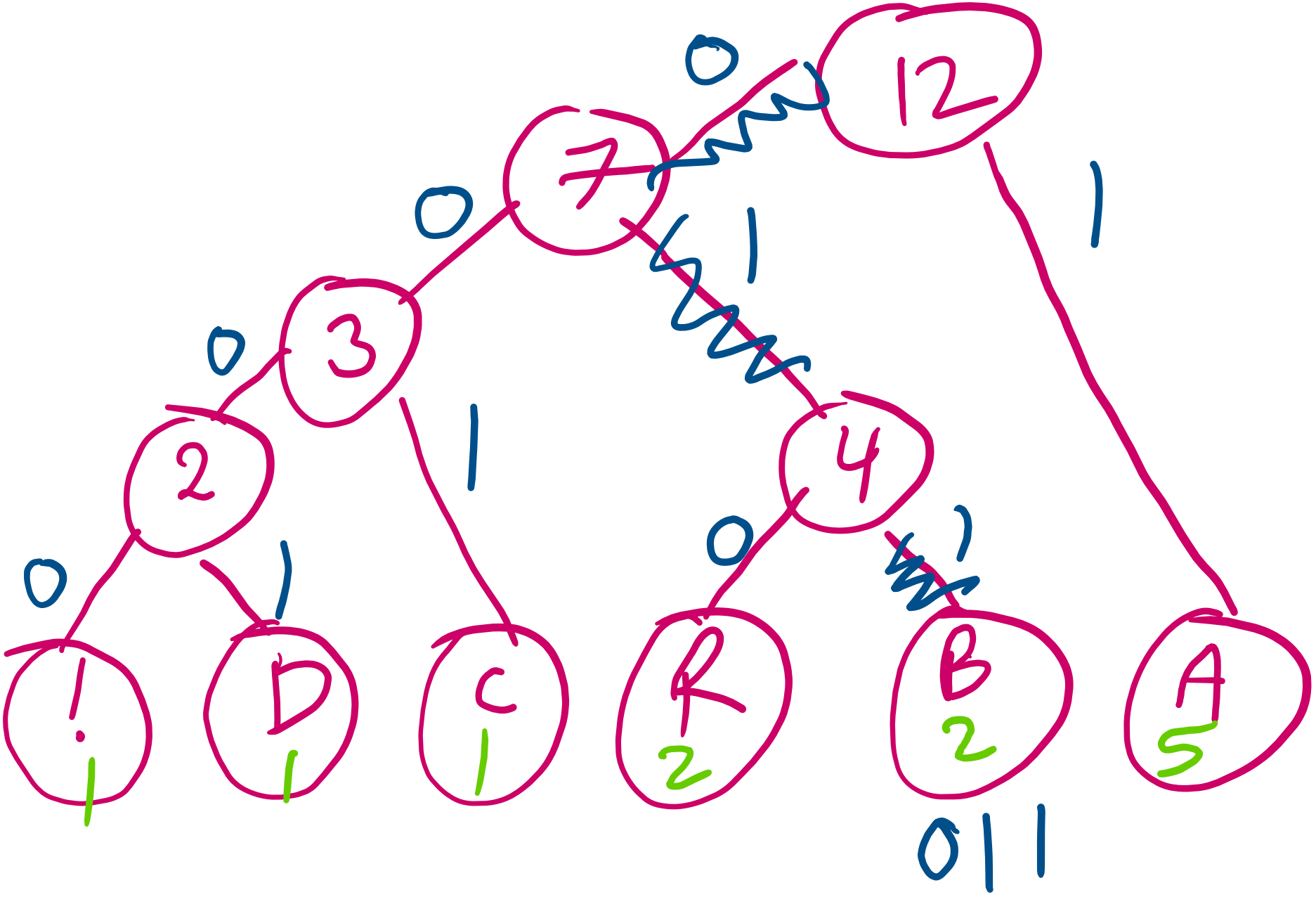

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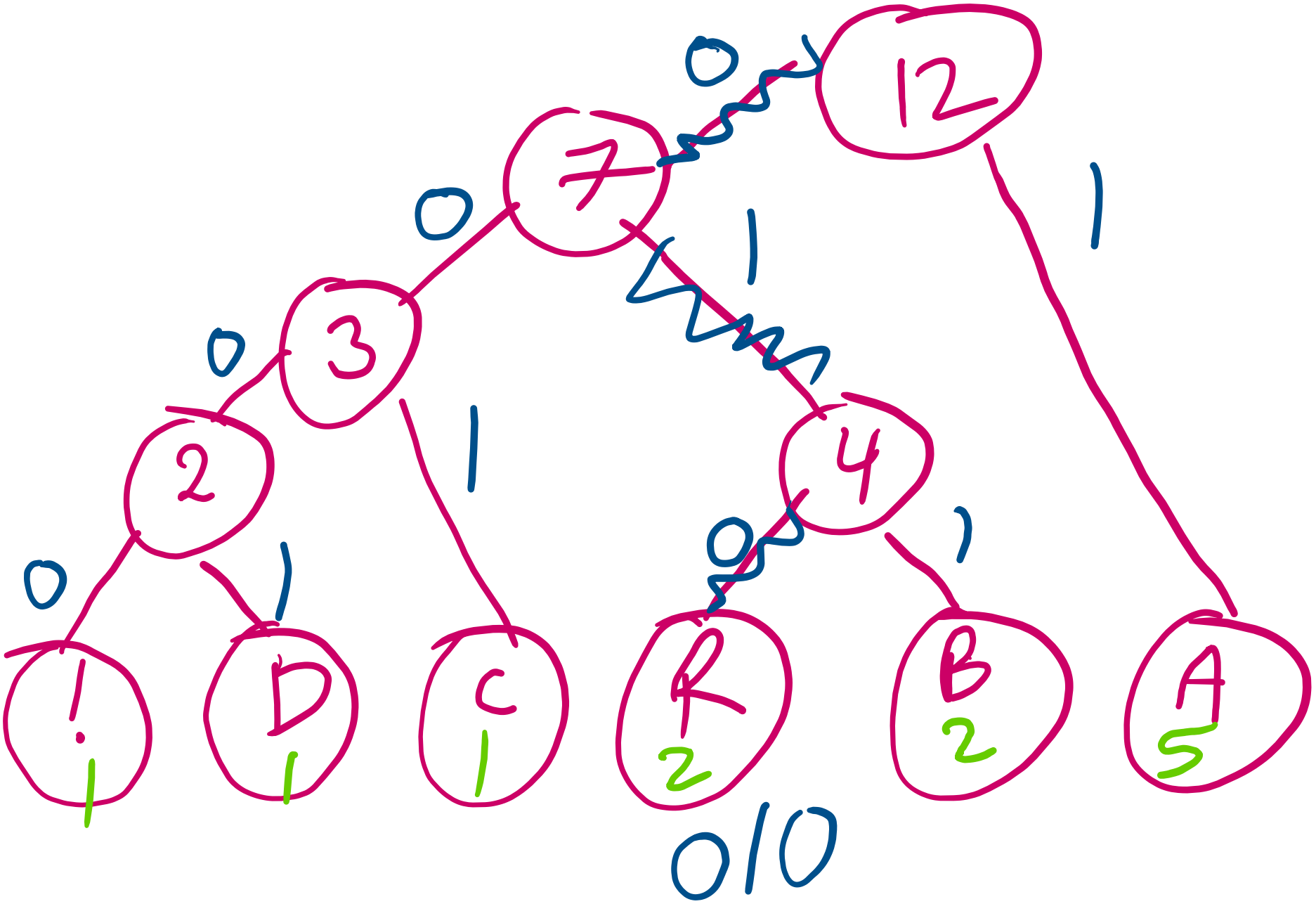

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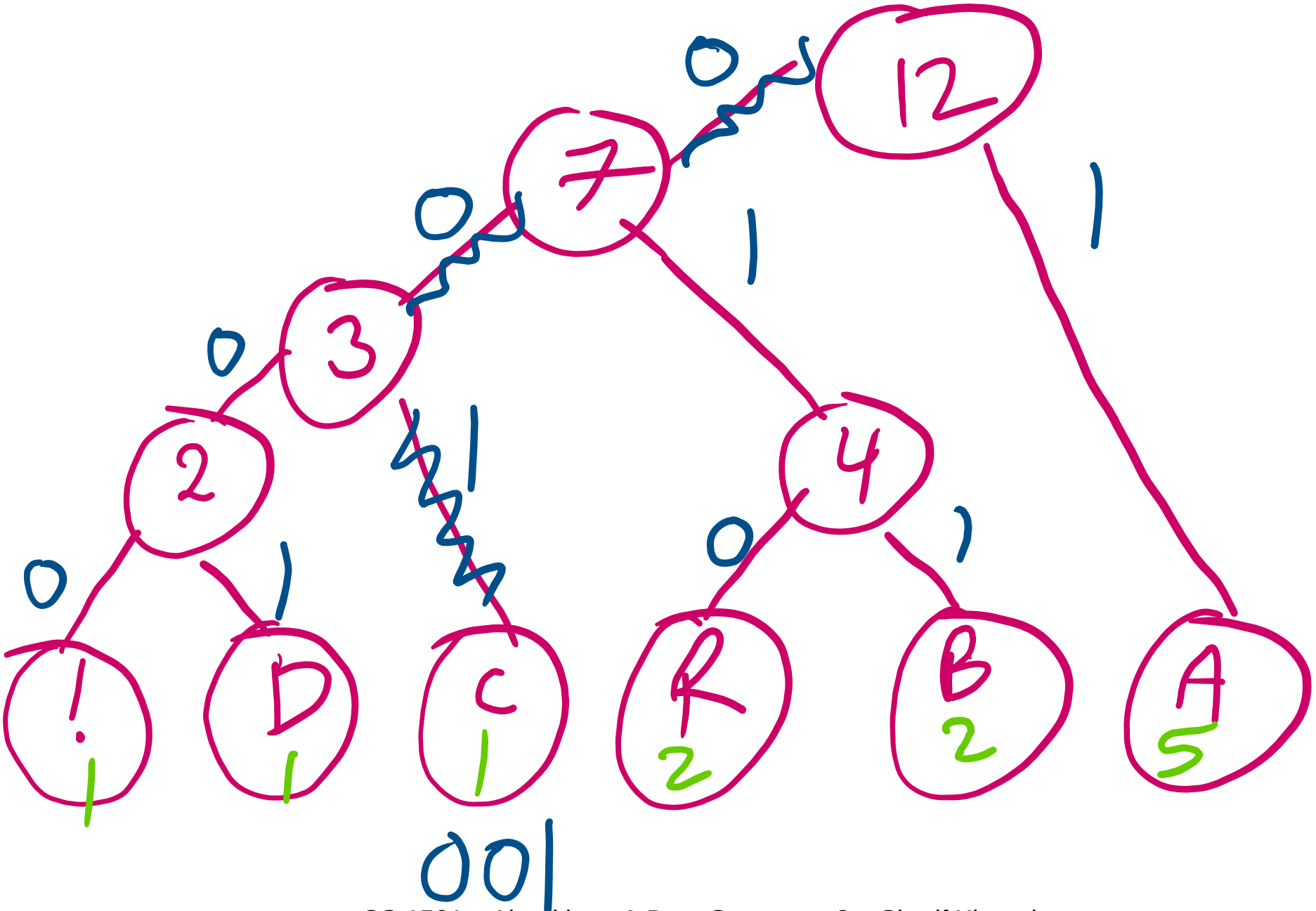

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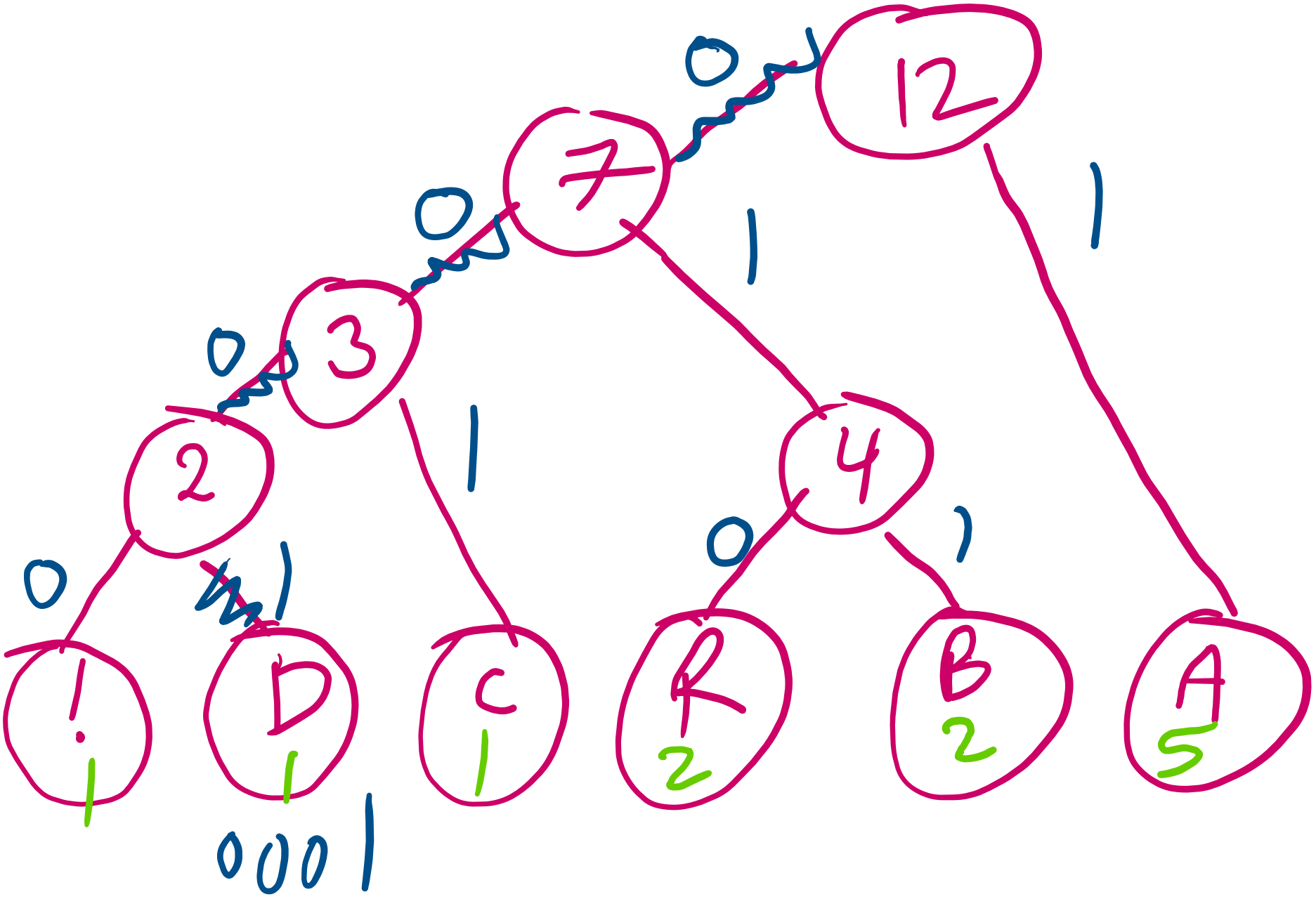

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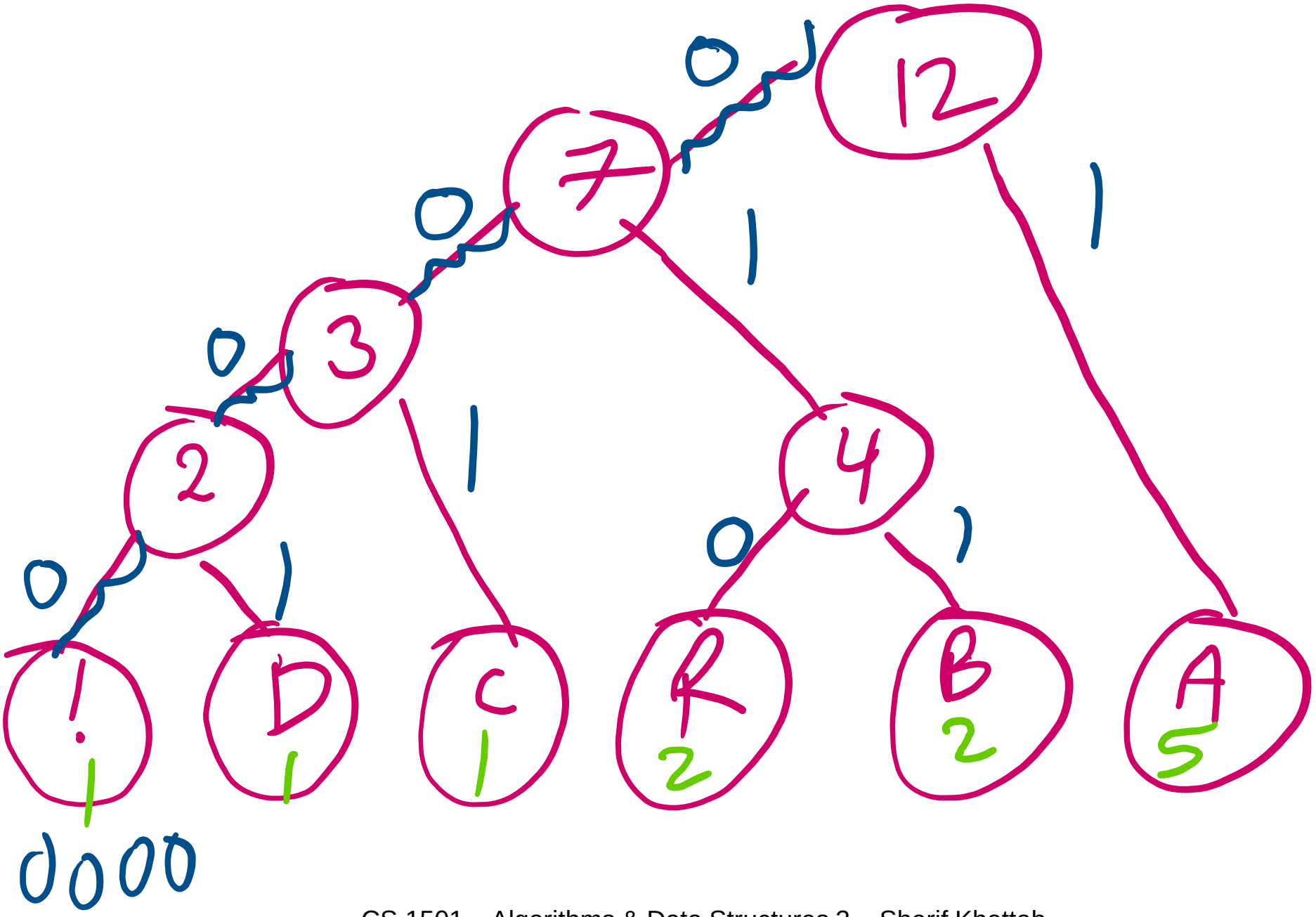

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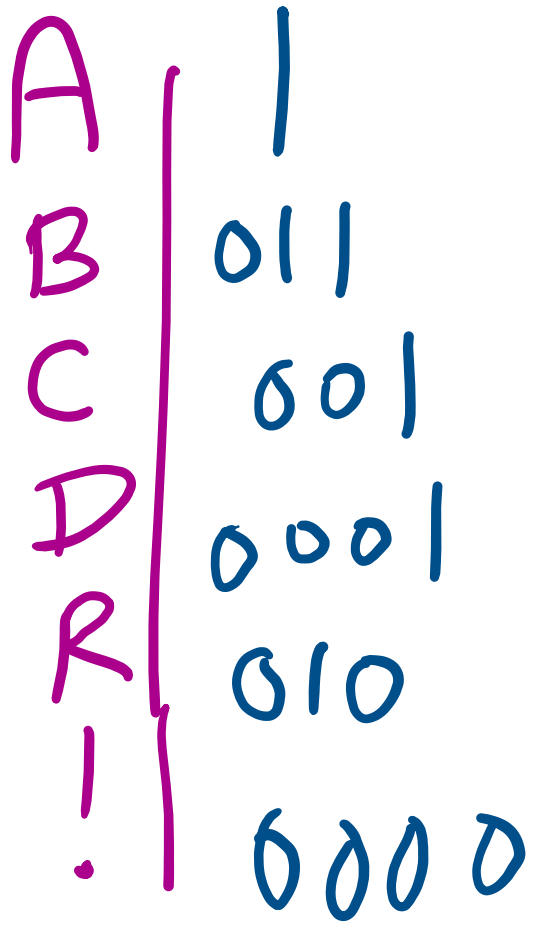

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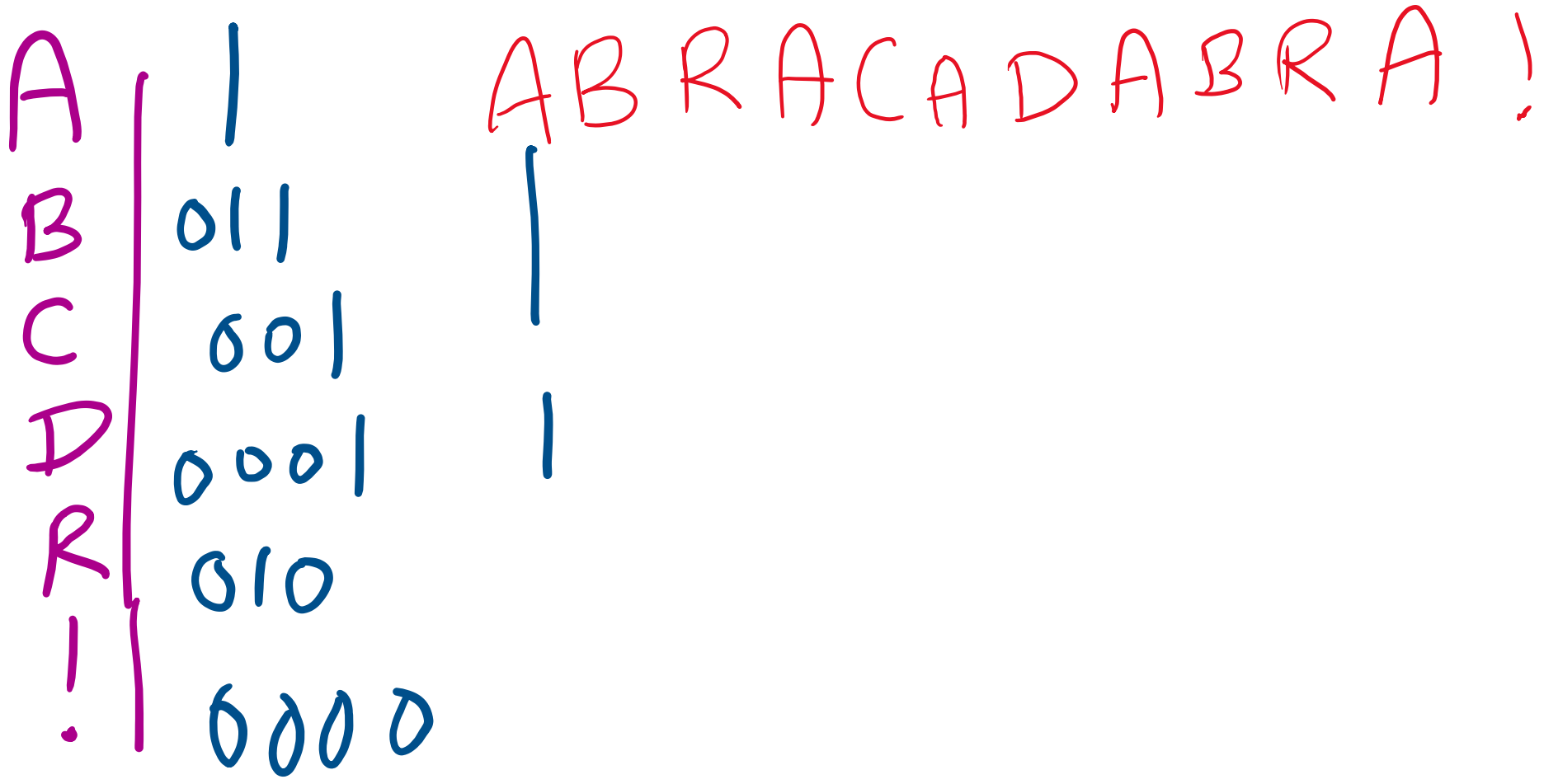

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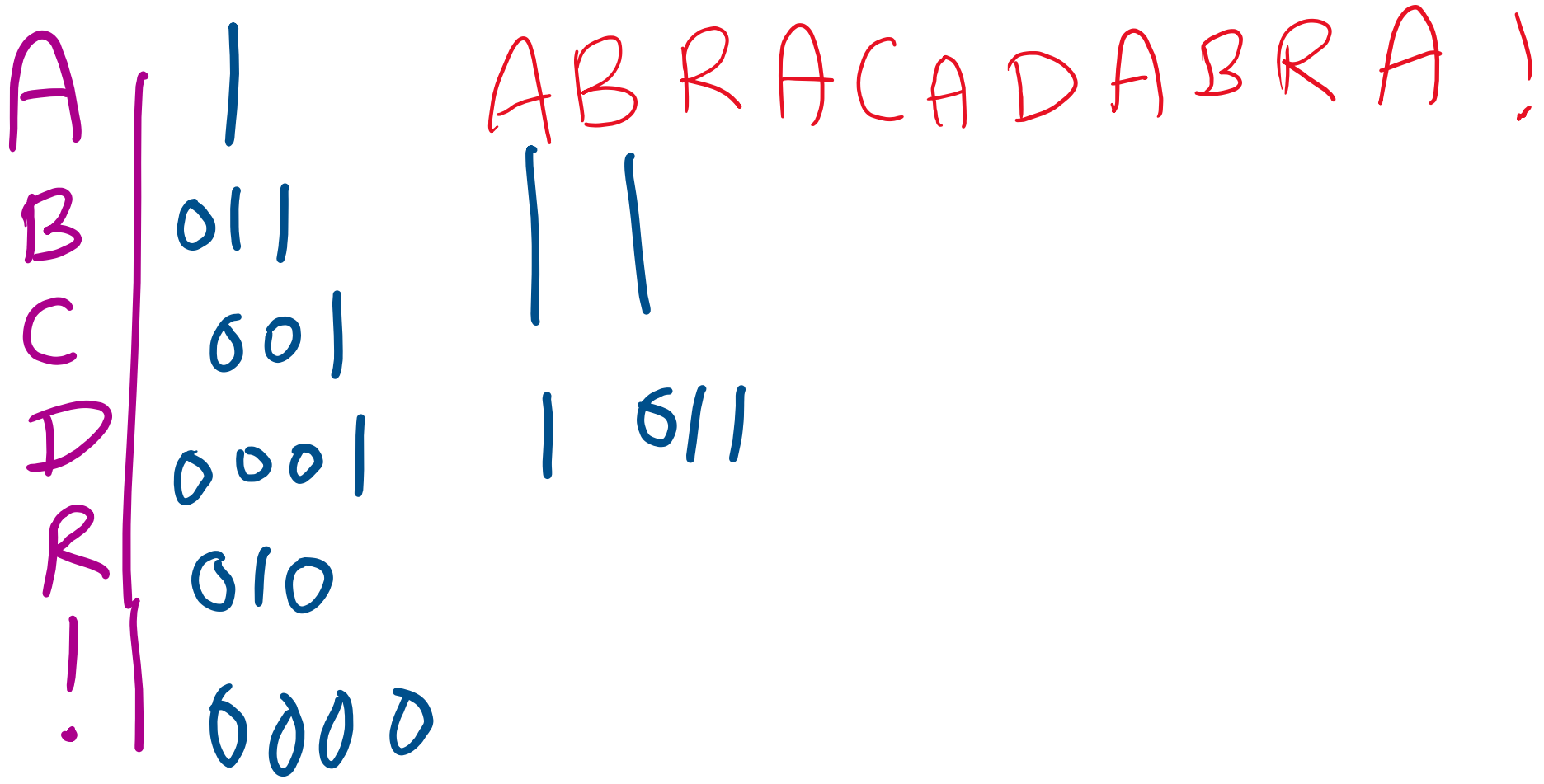

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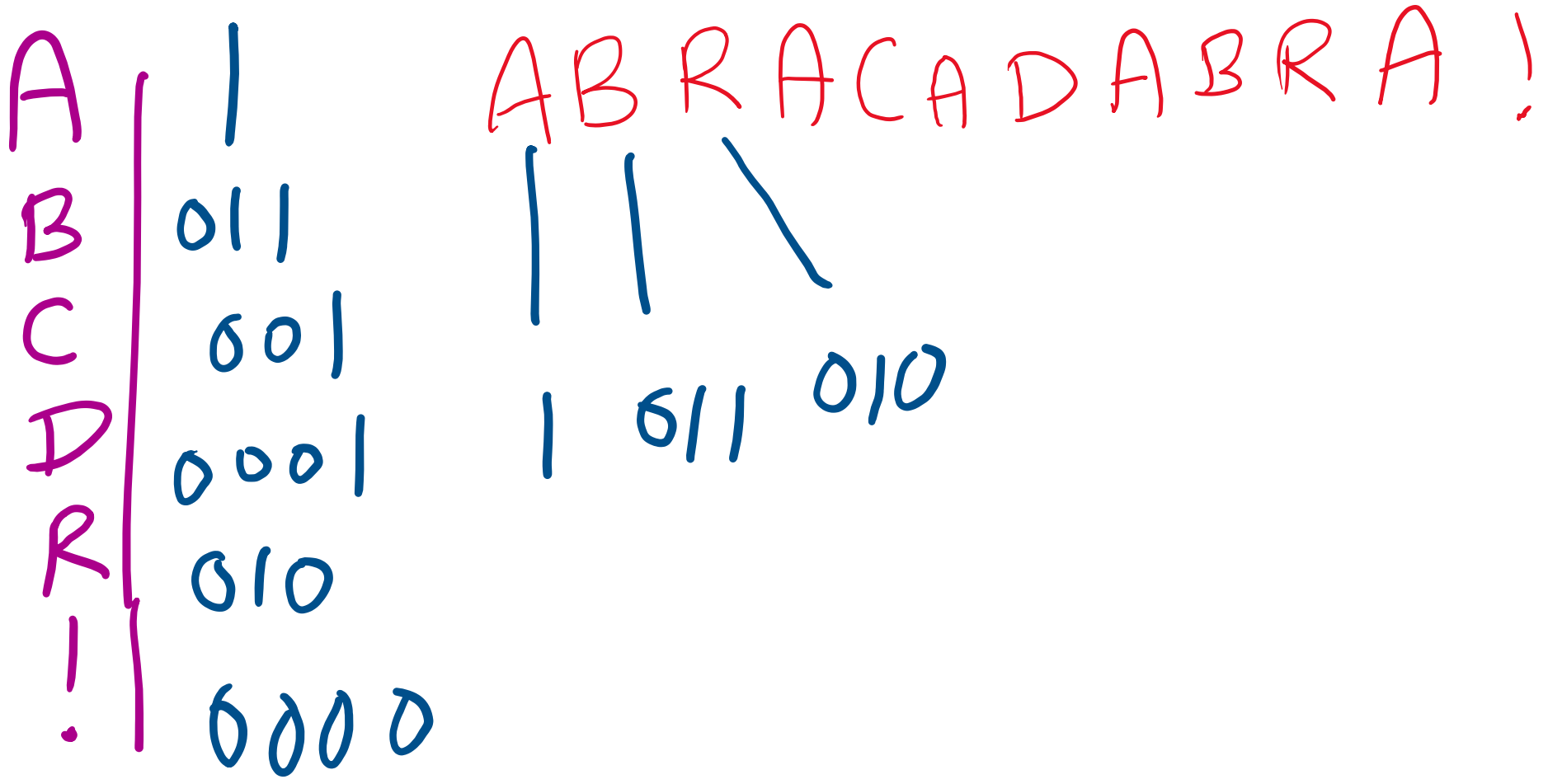

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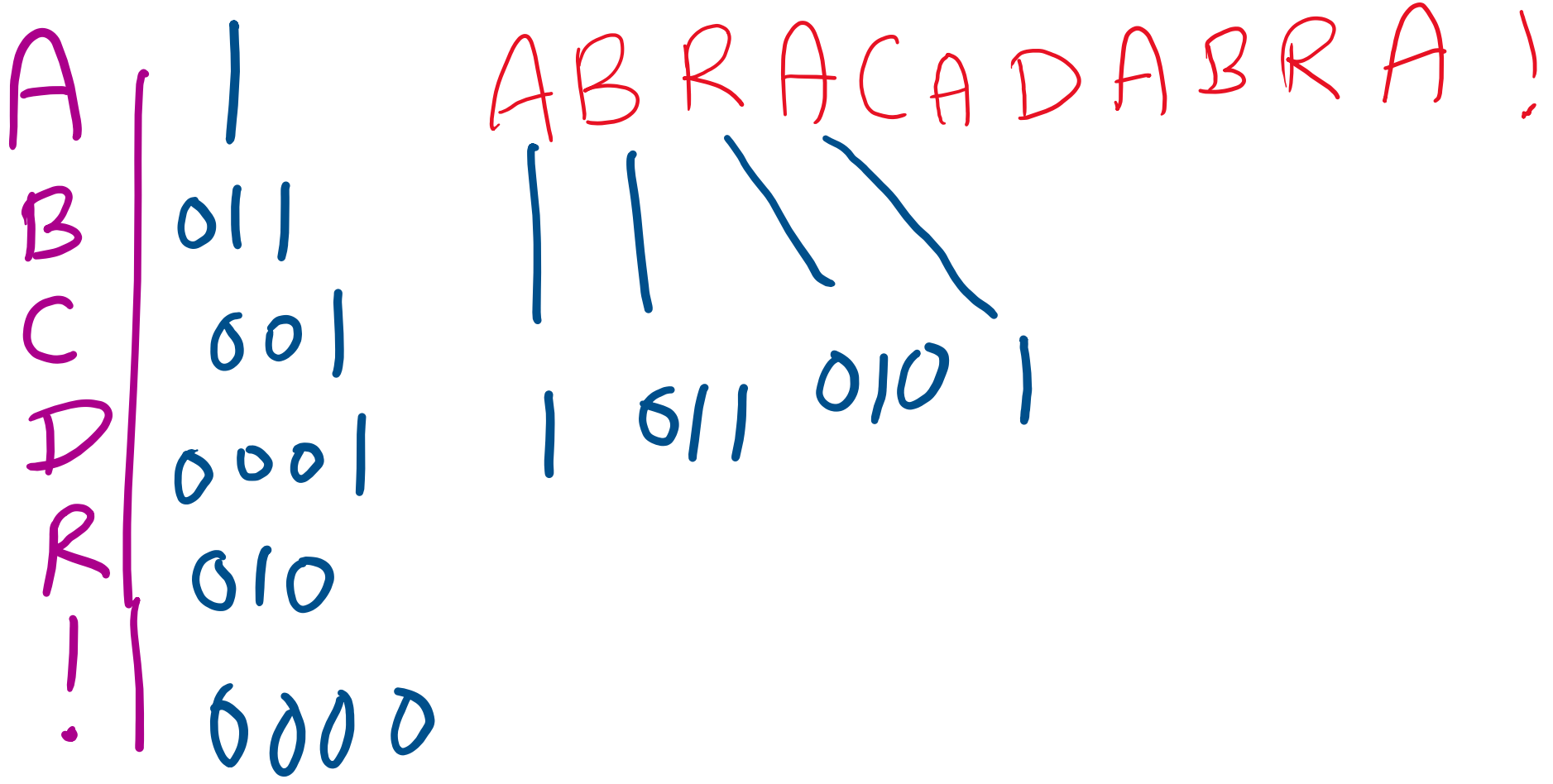

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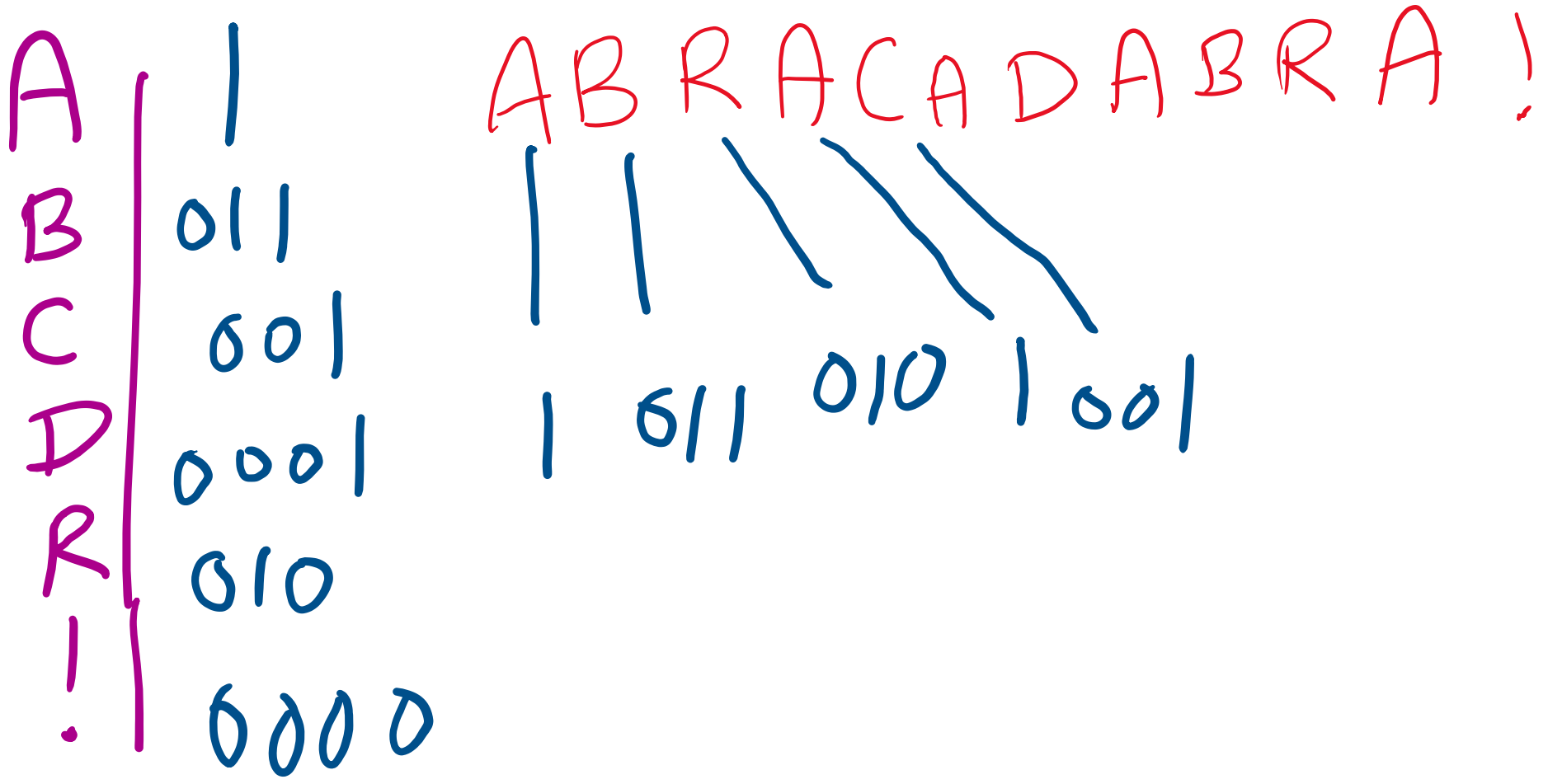

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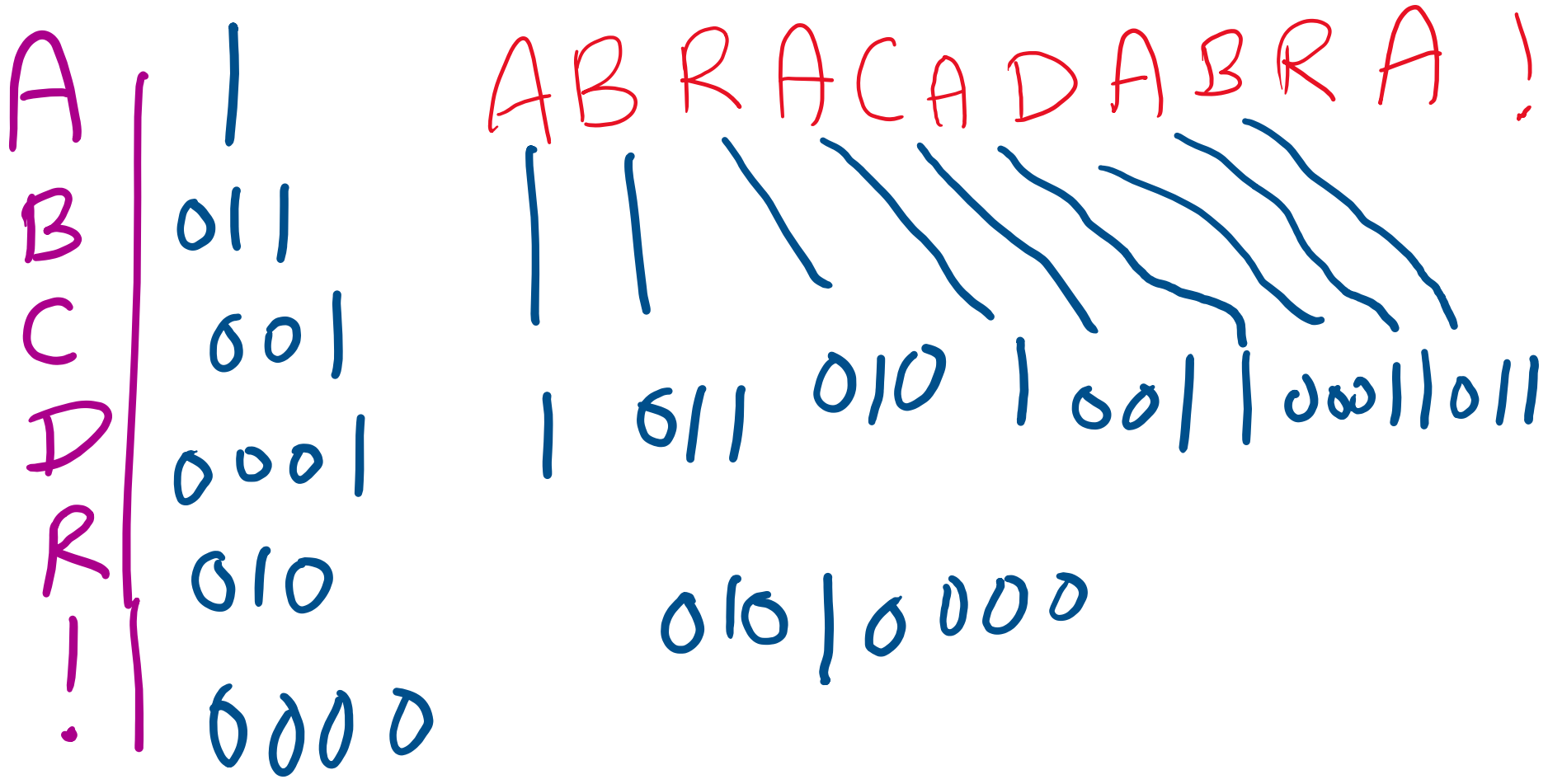

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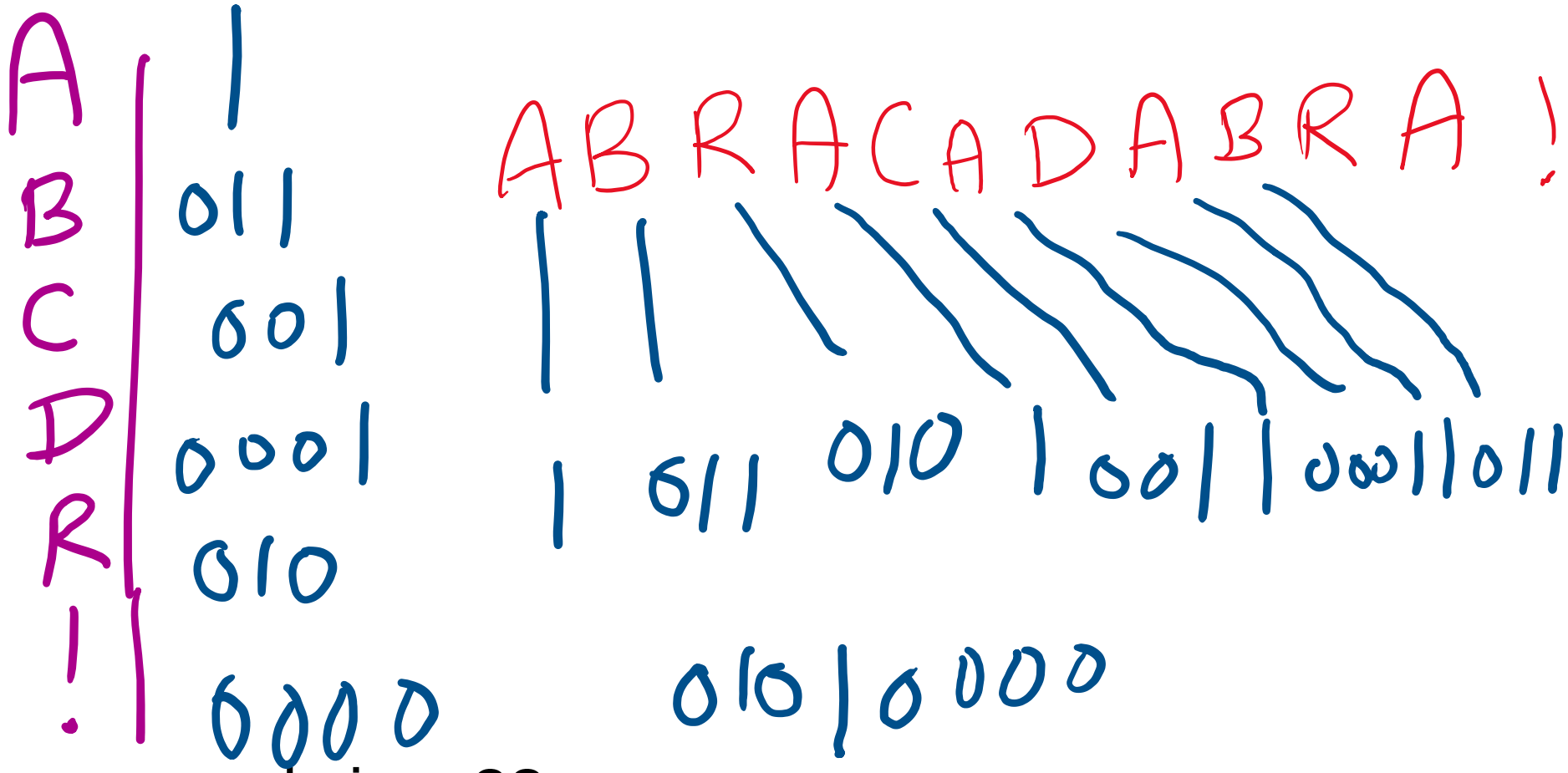
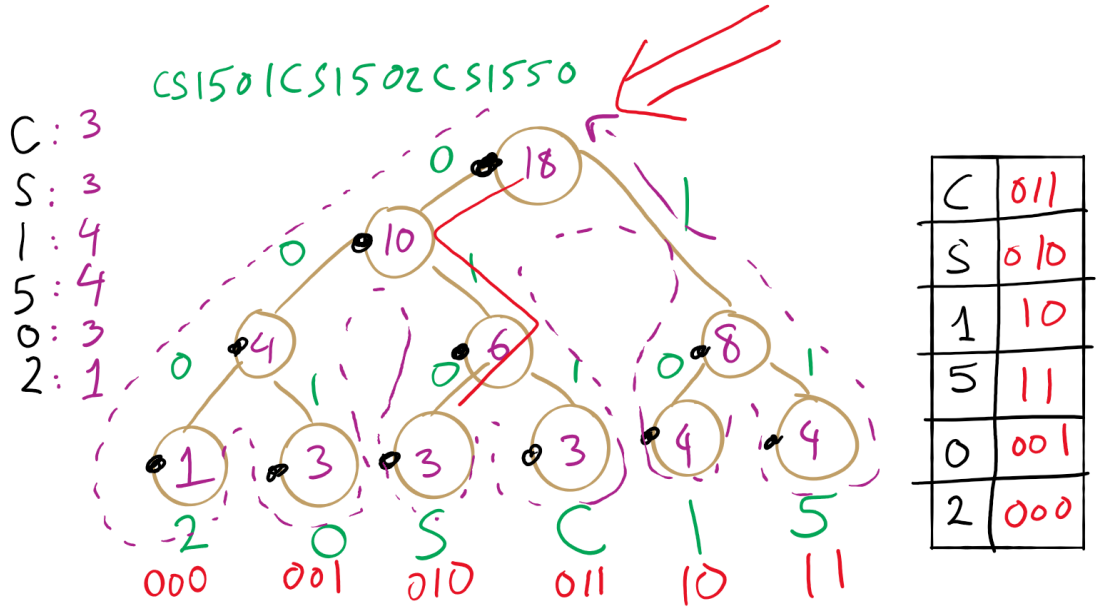


- Compressed size: 28
- Original size: 12*8 = 96 bits
- Compression ratio = 28/96

Huffman Compression Example



C	011
S	010
1	10
5	11
0	001
2	000

C S 1 5 0 ! C S 1 5 0 2 C S 1 5 5 0

011 010 10 11 001 10 011 010 10 11 001 000 011 010 10 11 11 001

Trie

0001 [ASCII for 2] 1 [ASCII for 0] 1 [ASCII for S] - - — — —

CS1

Implementation concerns

- Need to efficiently be able to select lowest weight trees to merge when constructing the trie
  - Can accomplish this using a *priority queue*
- Need to be able to read/write bitstrings!
  - Unless we pick multiples of 8 bits for our codewords, we will need to read/write *fractions* of bytes for our codewords
    - We're not actually going to do I/O on fraction of bytes
    - We'll maintain a buffer of bytes and perform bit processing on this buffer
    - See BinaryStdIn.java and BinaryStdOut.java

We need to read and write individual bits: Binary I/O

```
private static void writeBit(boolean bit) {
      // add bit to buffer by shifting in a zero
      buffer <<= 1;
      if (bit) buffer |= 1;  //then turning it to one if needed
      // if buffer is full (8 bits), write out as a single byte
      N++;
      if (N == 8) clearBuffer();
}
```

```
writeBit(true);
writeBit(false);
writeBit(true);
writeBit(false);
writeBit(false);
writeBit(false);
writeBit(false);
writeBit(true);
```

buffer: **00000000**

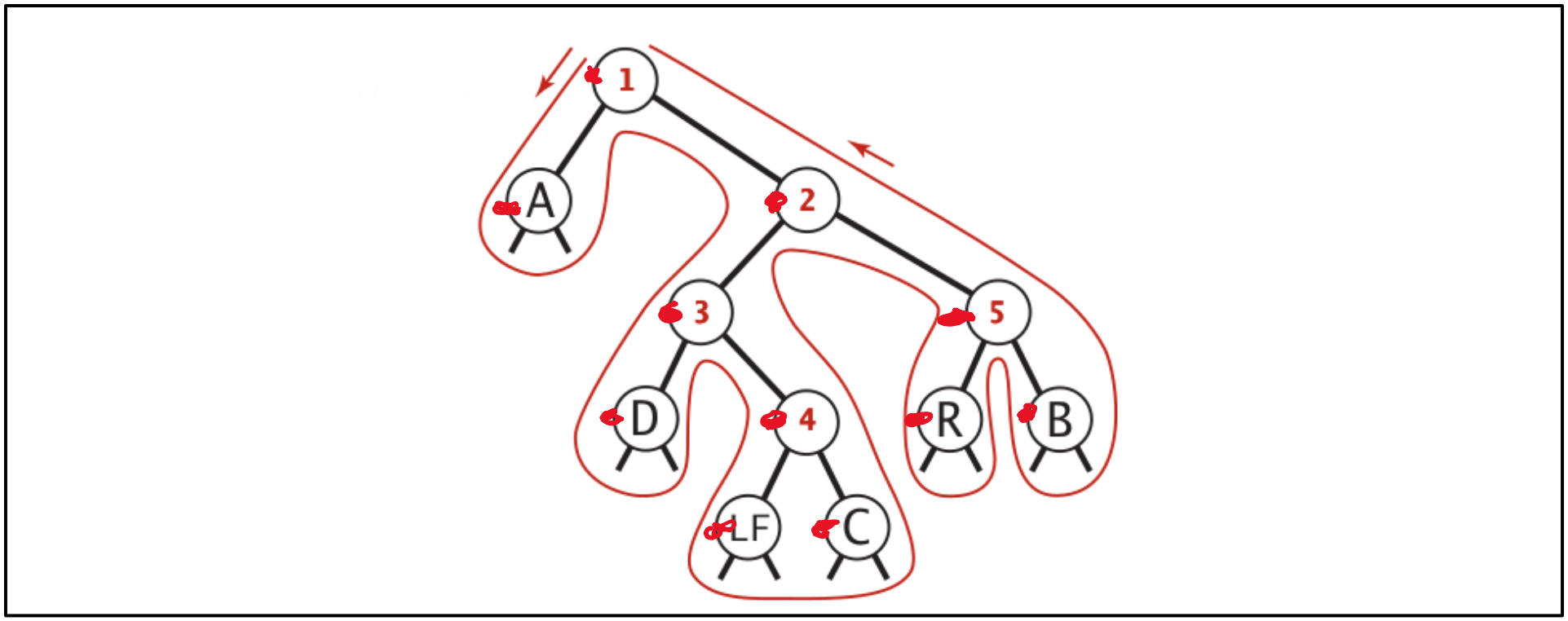
N: **0**

Further implementation concerns

- To encode, we'll need to read in characters and output codes
- To decode, we'll need to read in codes and output characters
- Sounds like we'll need a symbol table!
  - What implementation would be best?
    - Same for encoding and decoding?
  - Note that this means we need access to the trie to expand a compressed file!
    - Let's store the trie in the compressed file
    - how?

Representing tries as bitstrings

Preorder traversal



internal node → 0

leaf node → 1 followed by ASCII code of char inside

Representing tries as bitstrings

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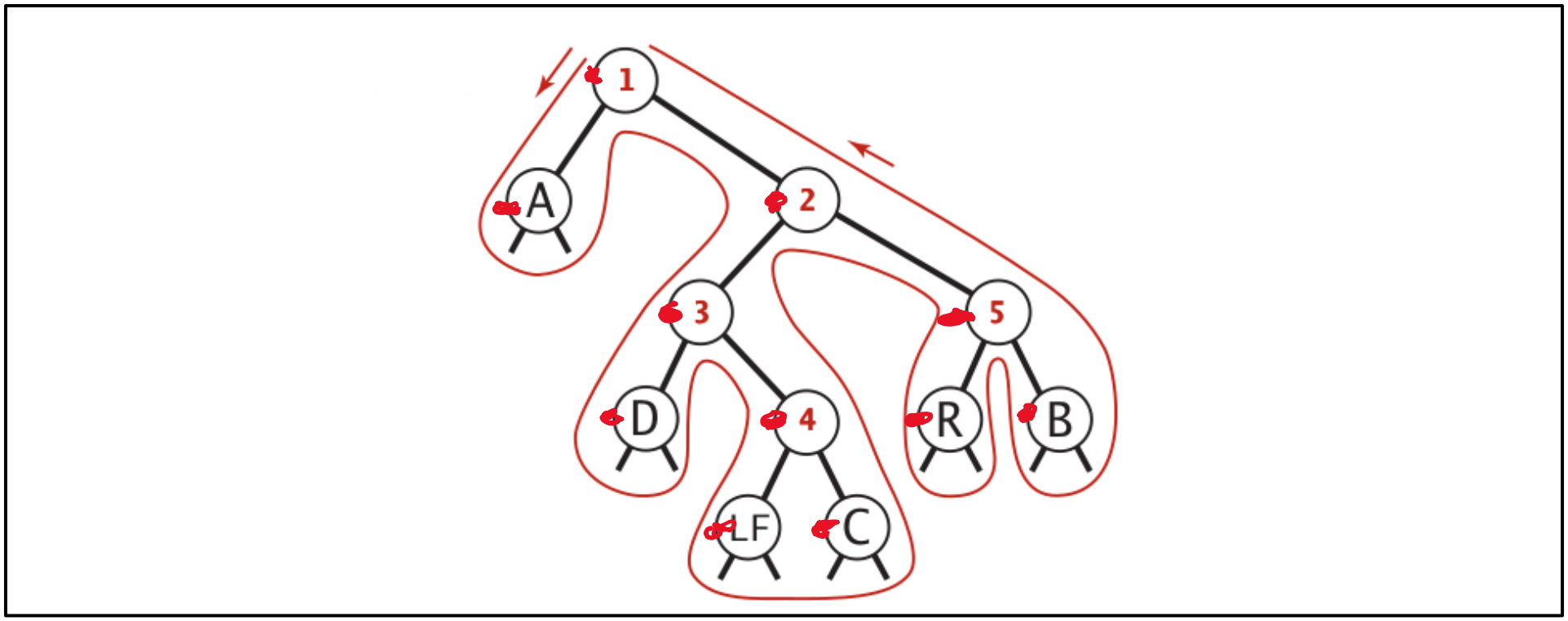

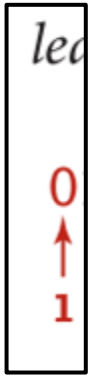

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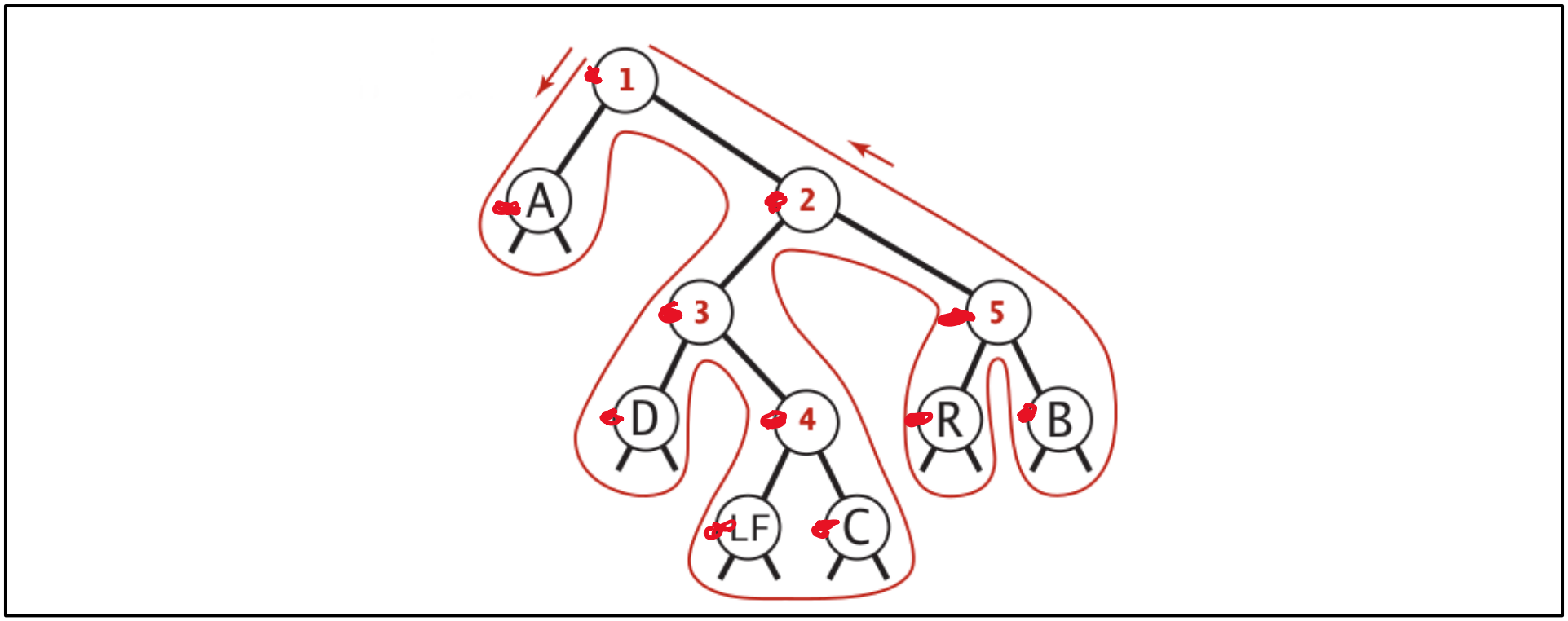

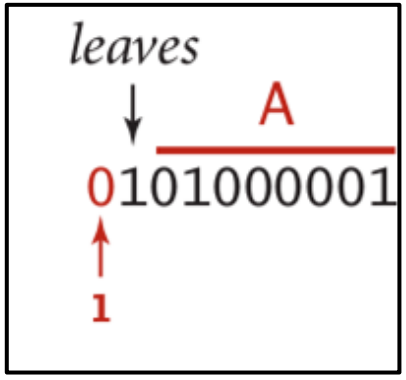

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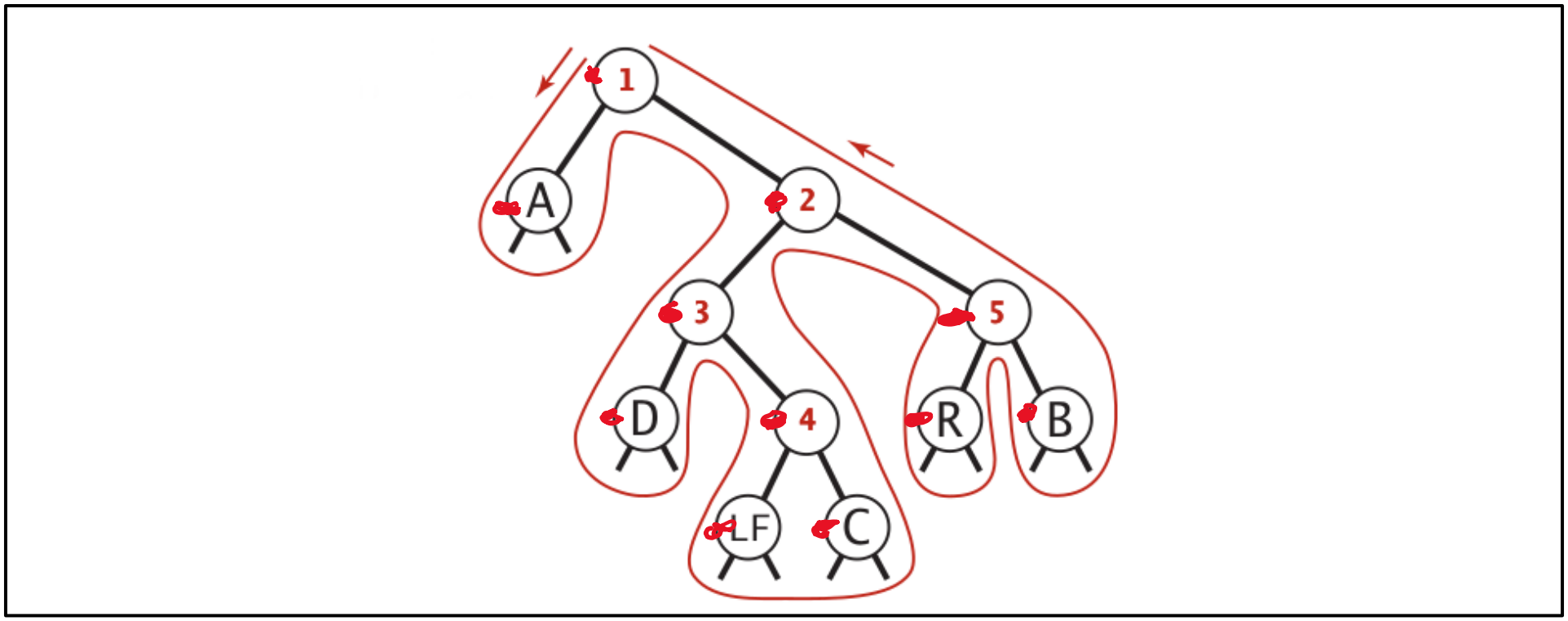

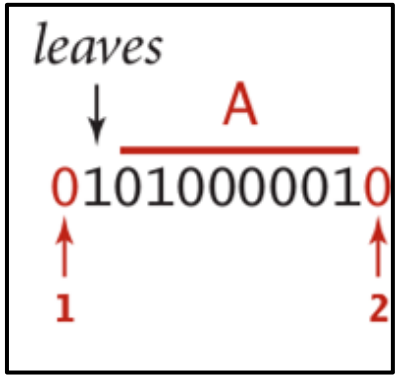

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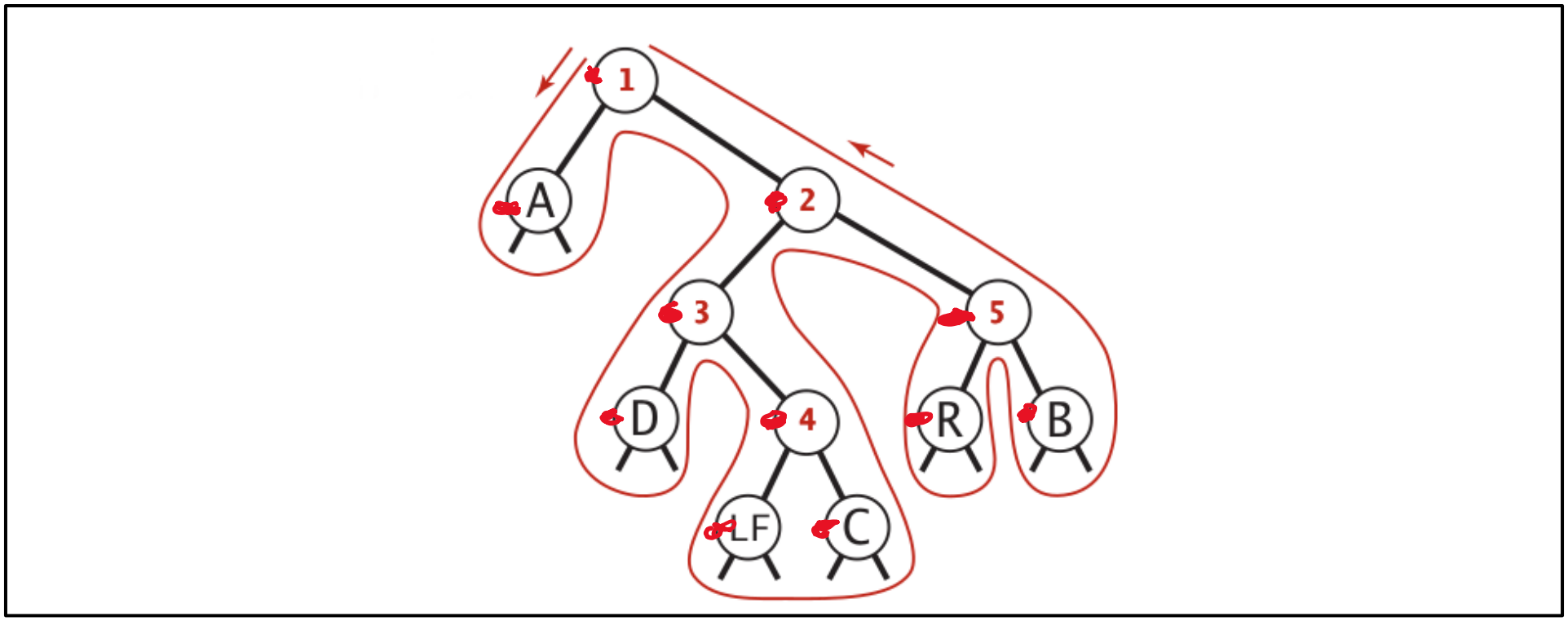

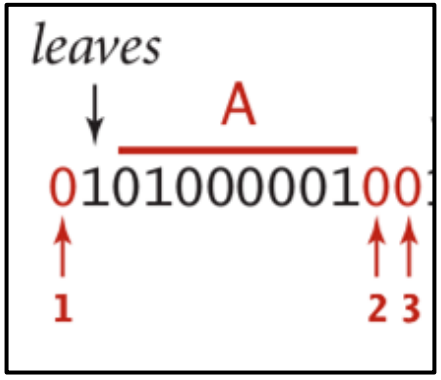

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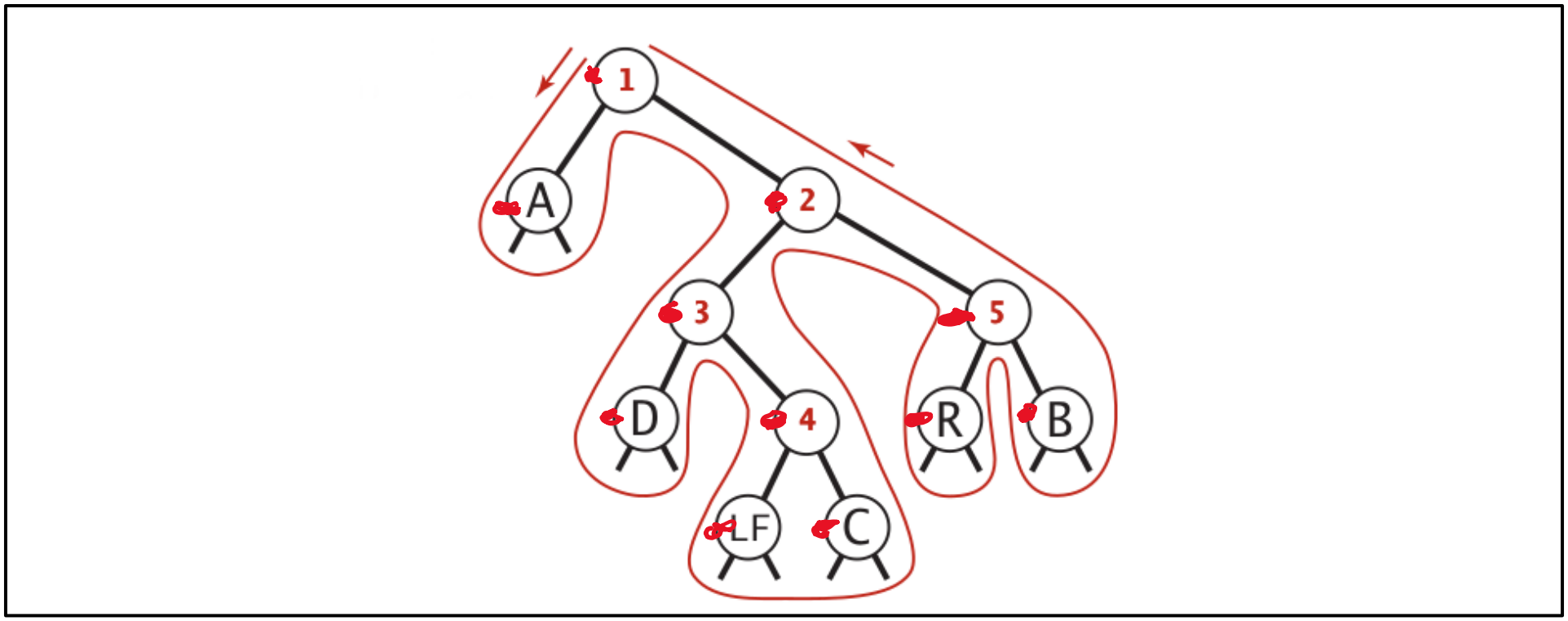

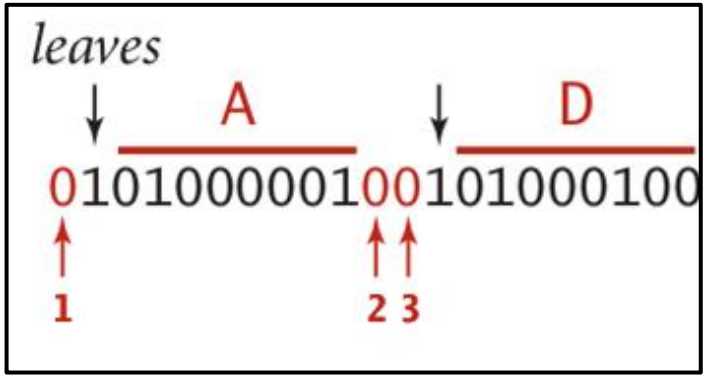

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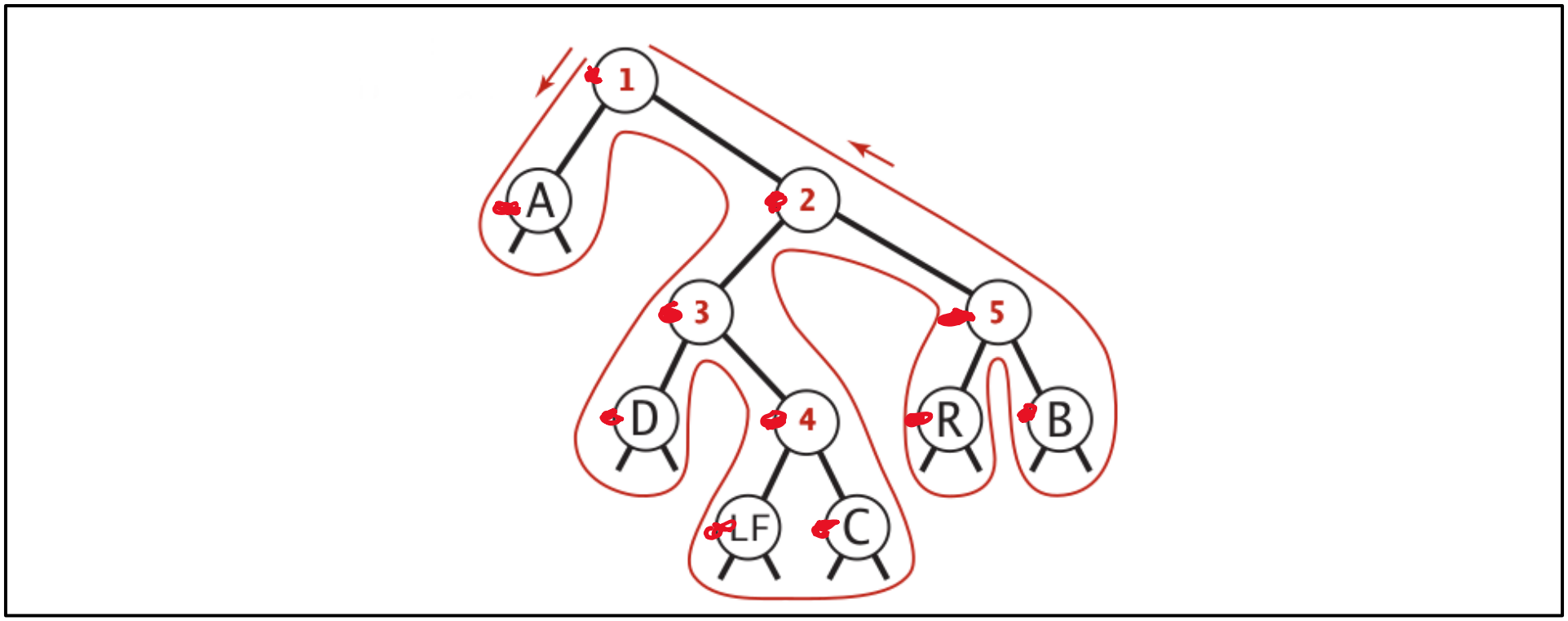

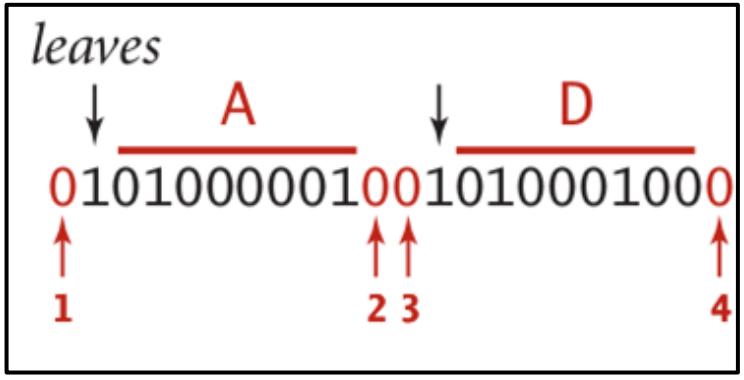

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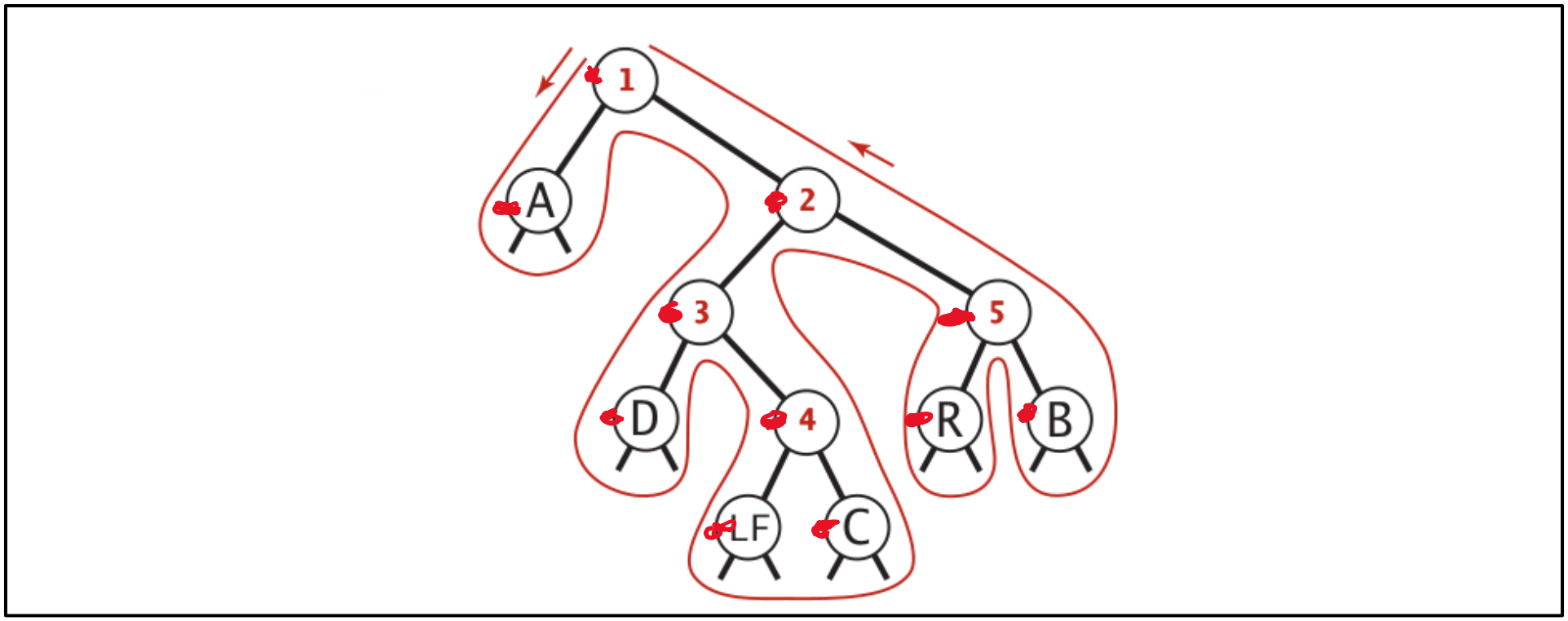

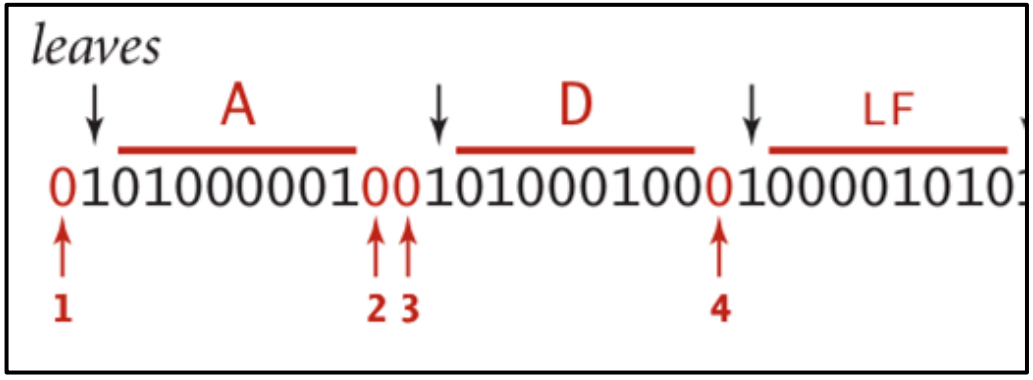

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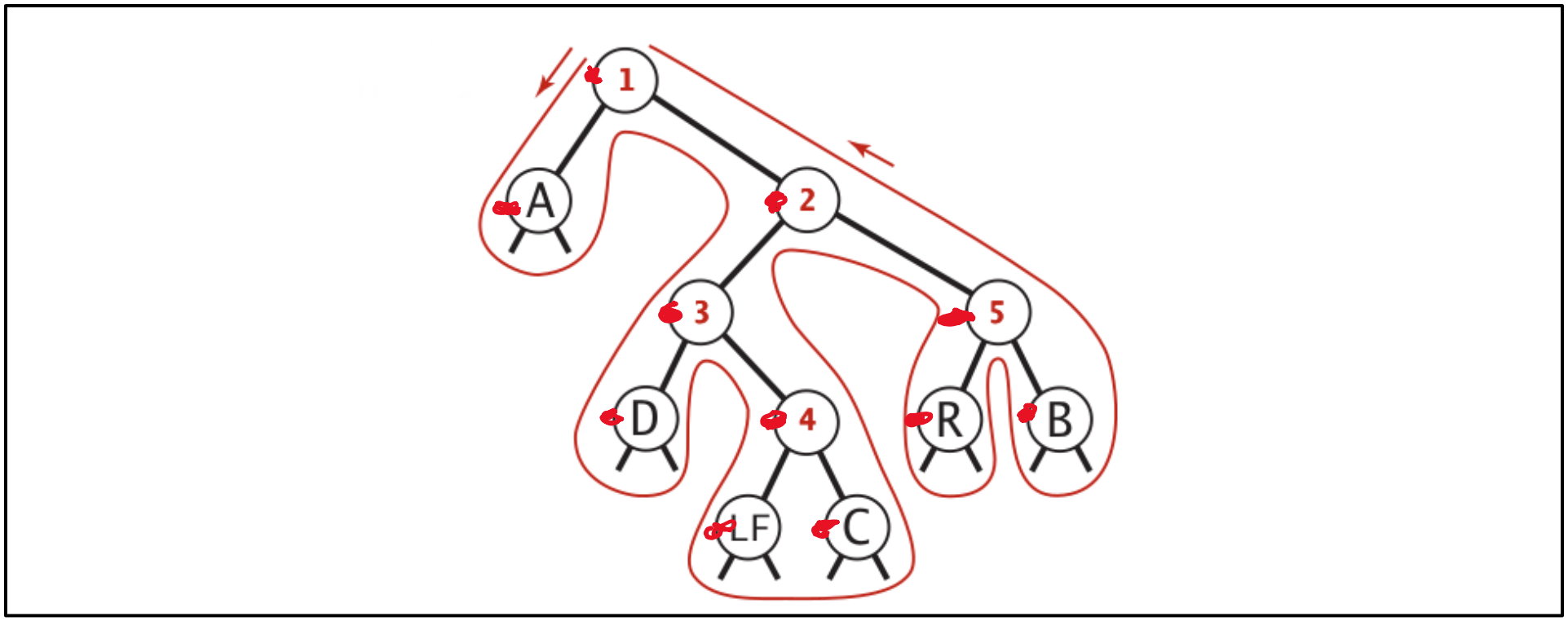

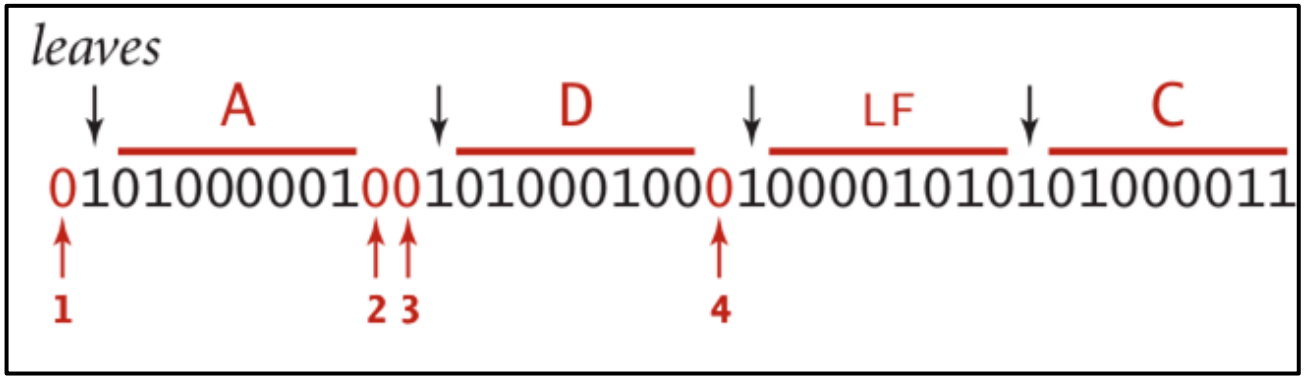

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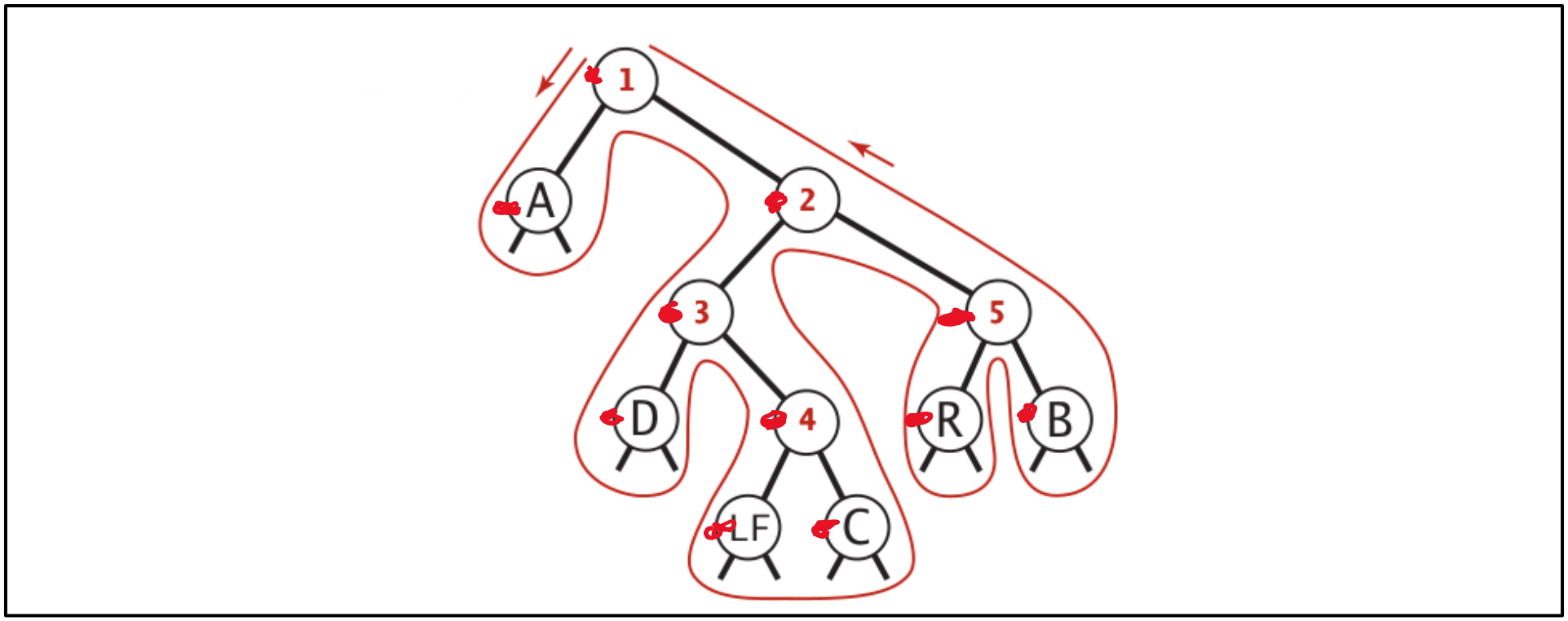

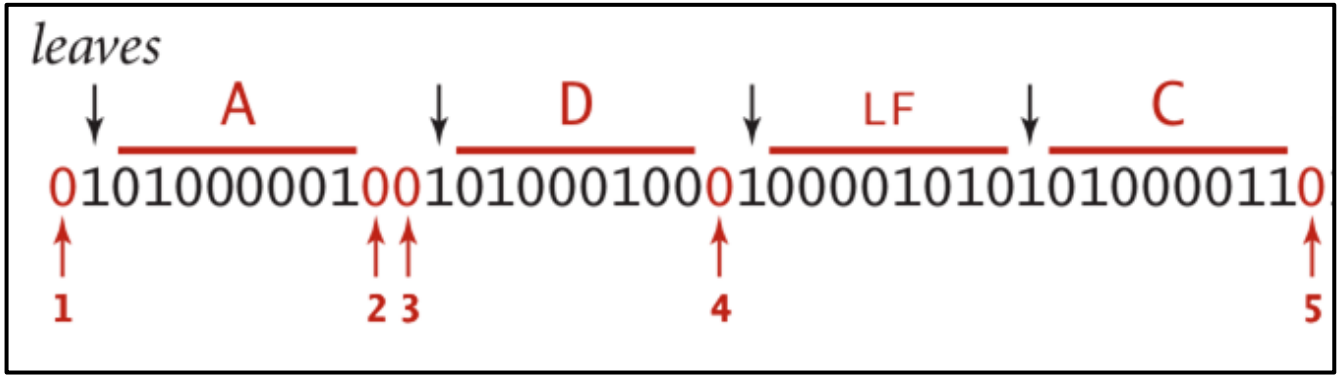

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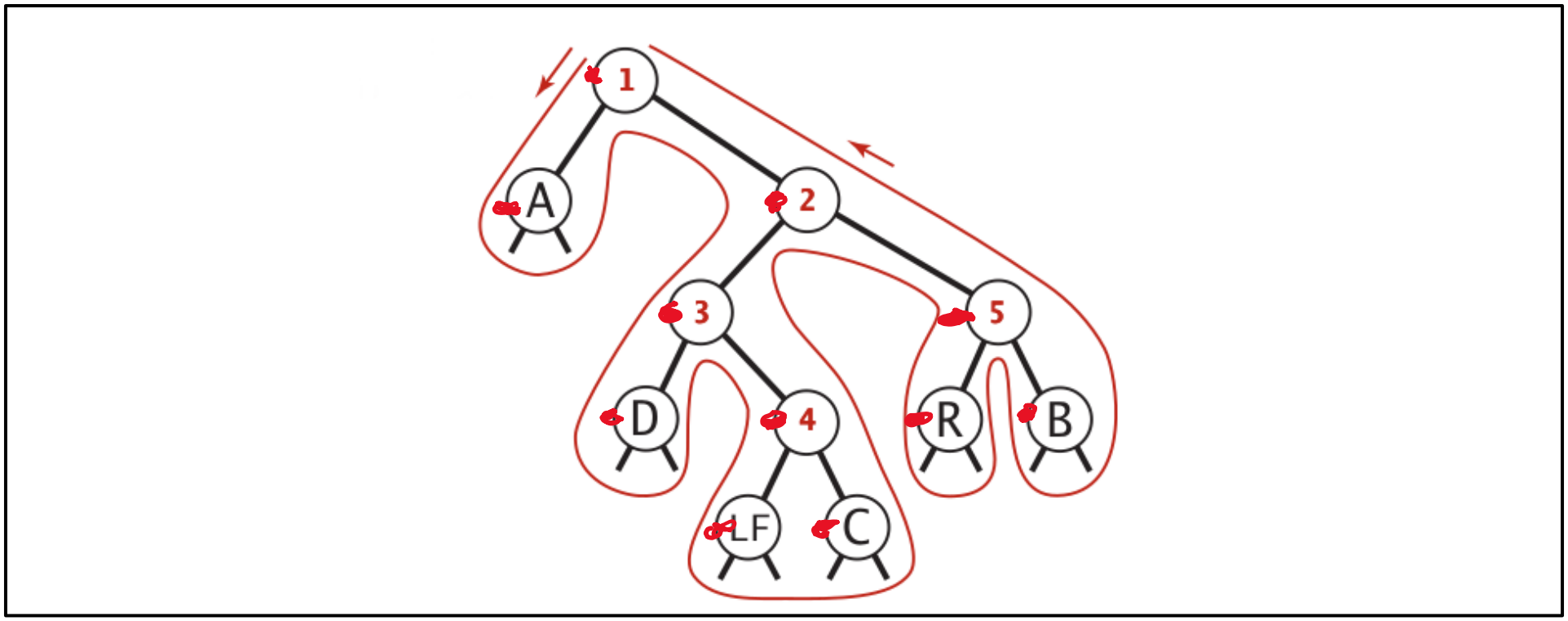

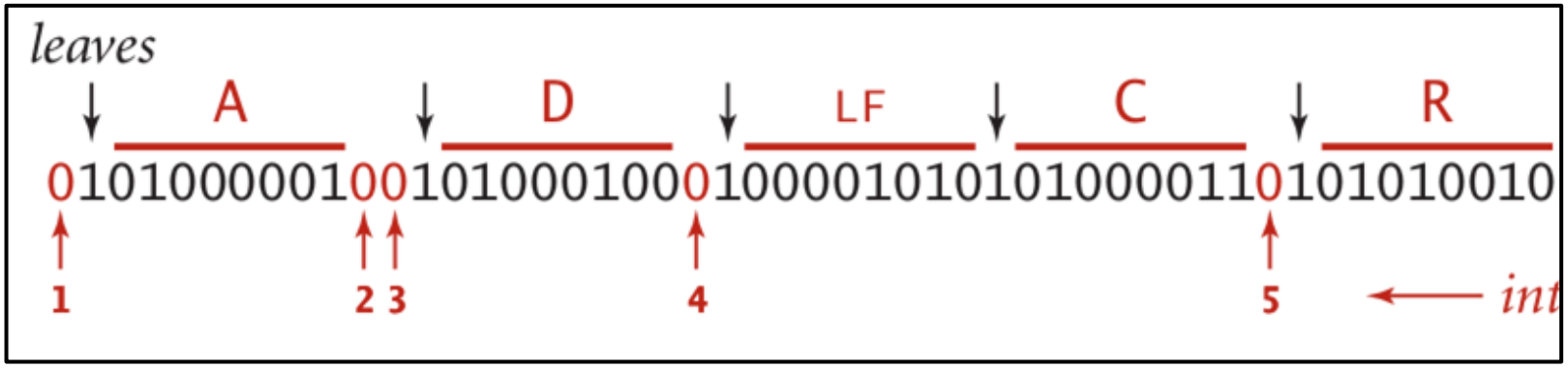

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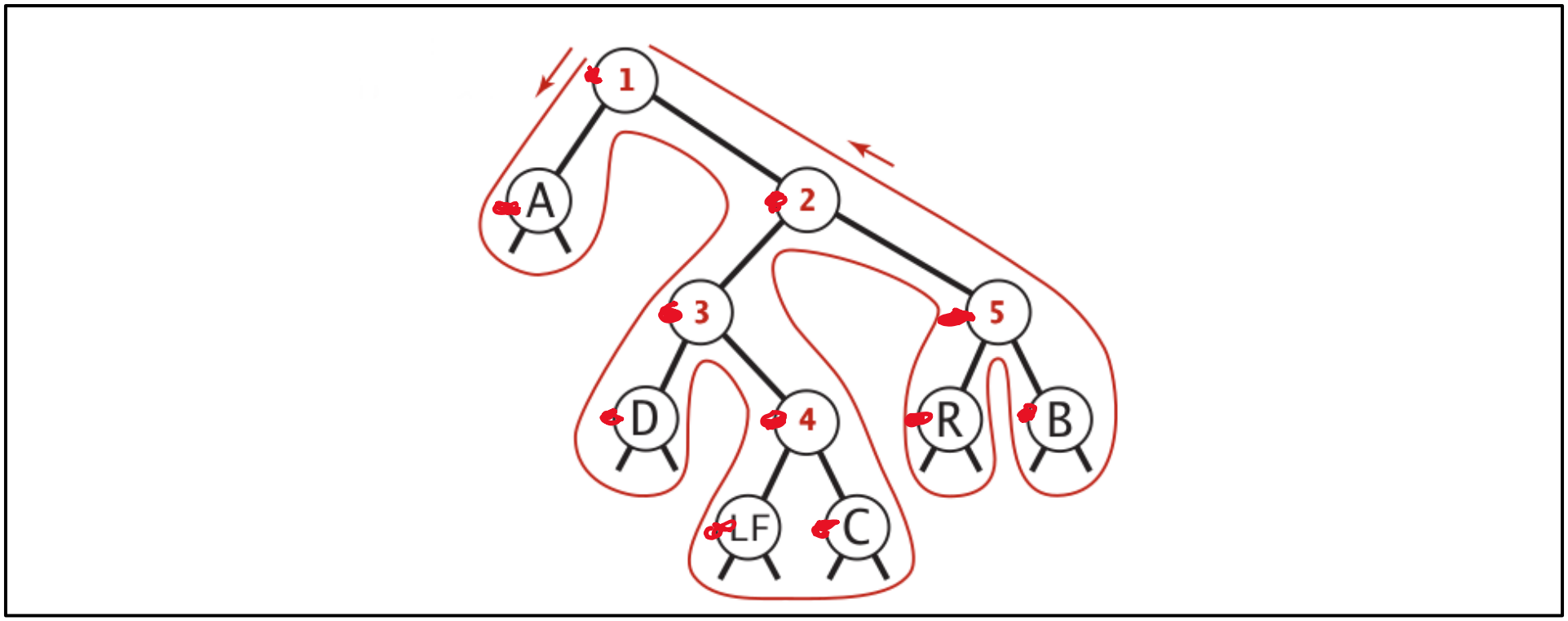
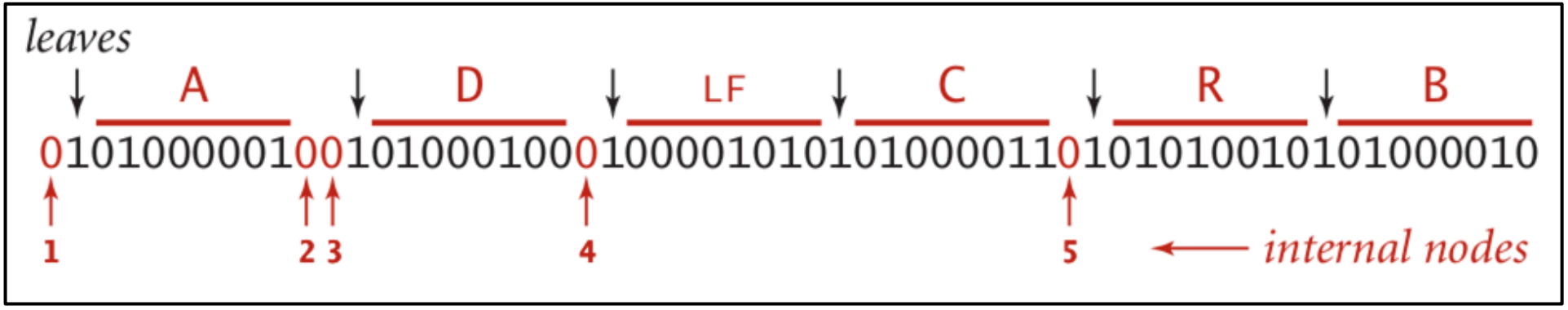




Writing a trie

```
private static void writeTrie(Node x){
   if (x.isLeaf()) {
      BinaryStdOut.write(true);
      BinaryStdOut.write(x.ch);
      return;
   }
   BinaryStdOut.write(false);
   writeTrie(x.left);
   writeTrie(x.right);
}
```

Reading a trie back

Similar to the read tree lab!

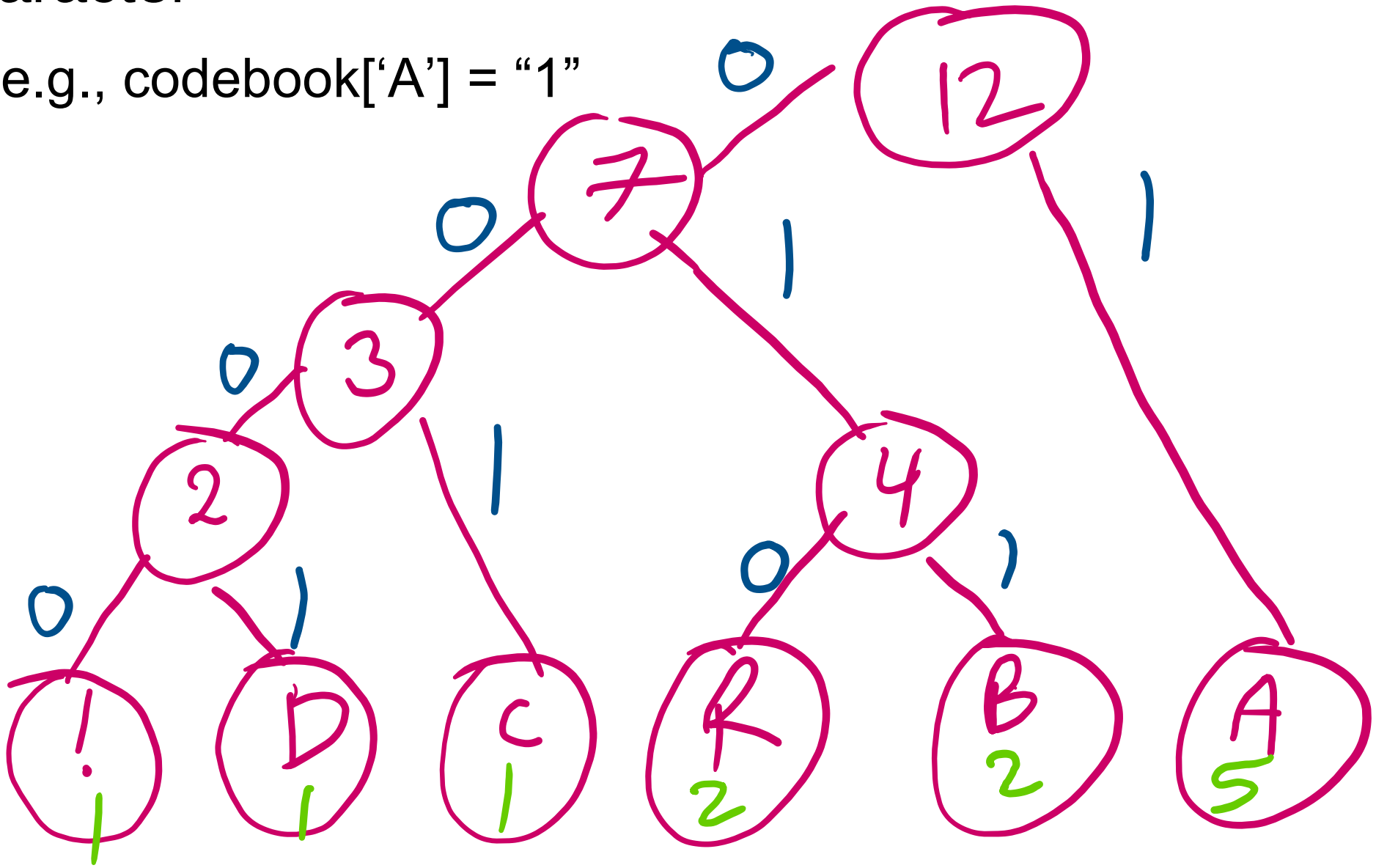
```
private static Node readTrie() {
  if (BinaryStdIn.readBoolean())
    return new
  Node(BinaryStdIn.readChar(), 0, null,
  null);
  return new Node('\0', 0, readTrie(),
readTrie());
}
```

Huffman pseudocode

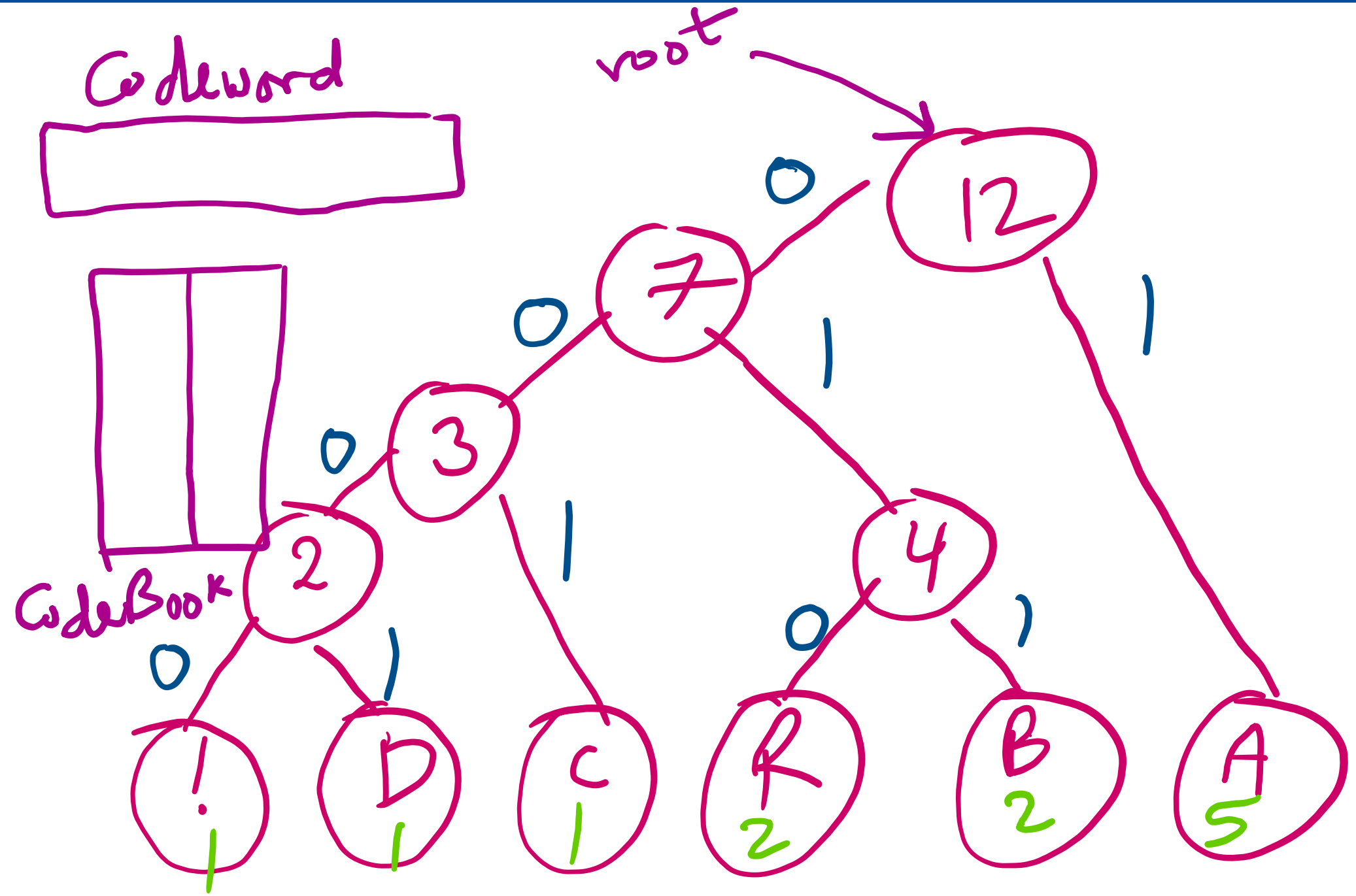
- Encoding approach:
  - Read input
  - Compute frequencies
  - Build trie/codeword table
  - Write out trie as a bitstring to compressed file
  - Write out character count of input (**why is that necessary**?)
  - Use table to write out the codeword for each input character
- Decoding approach:
  - Read trie
  - Read character count
  - Use trie to decode bitstring of compressed file

Huffman Compression: Generating the *Codebook*

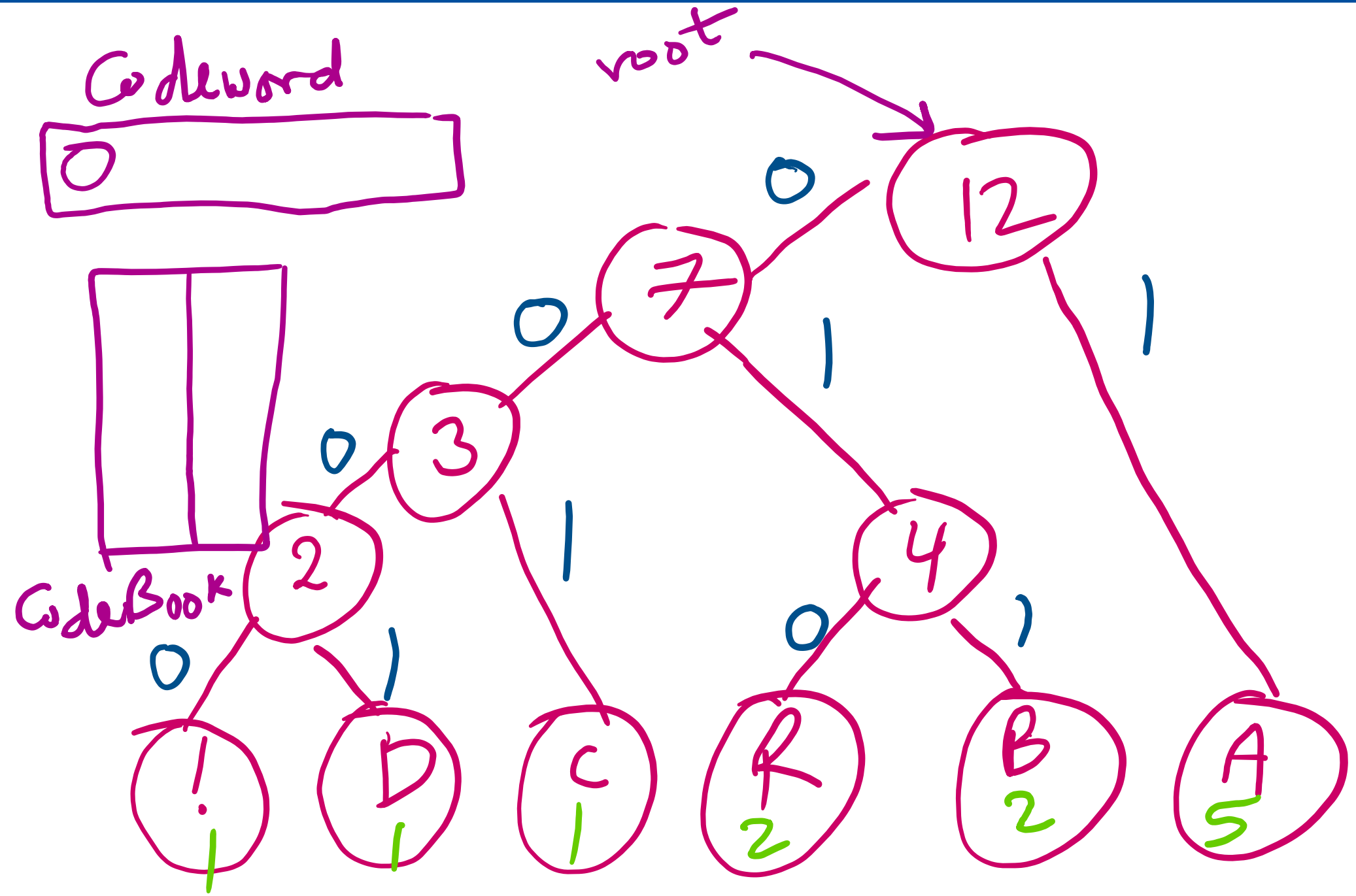
- The codebook is a table of codewords indexed by character
  - e.g., codebook[‘A’] = “1”



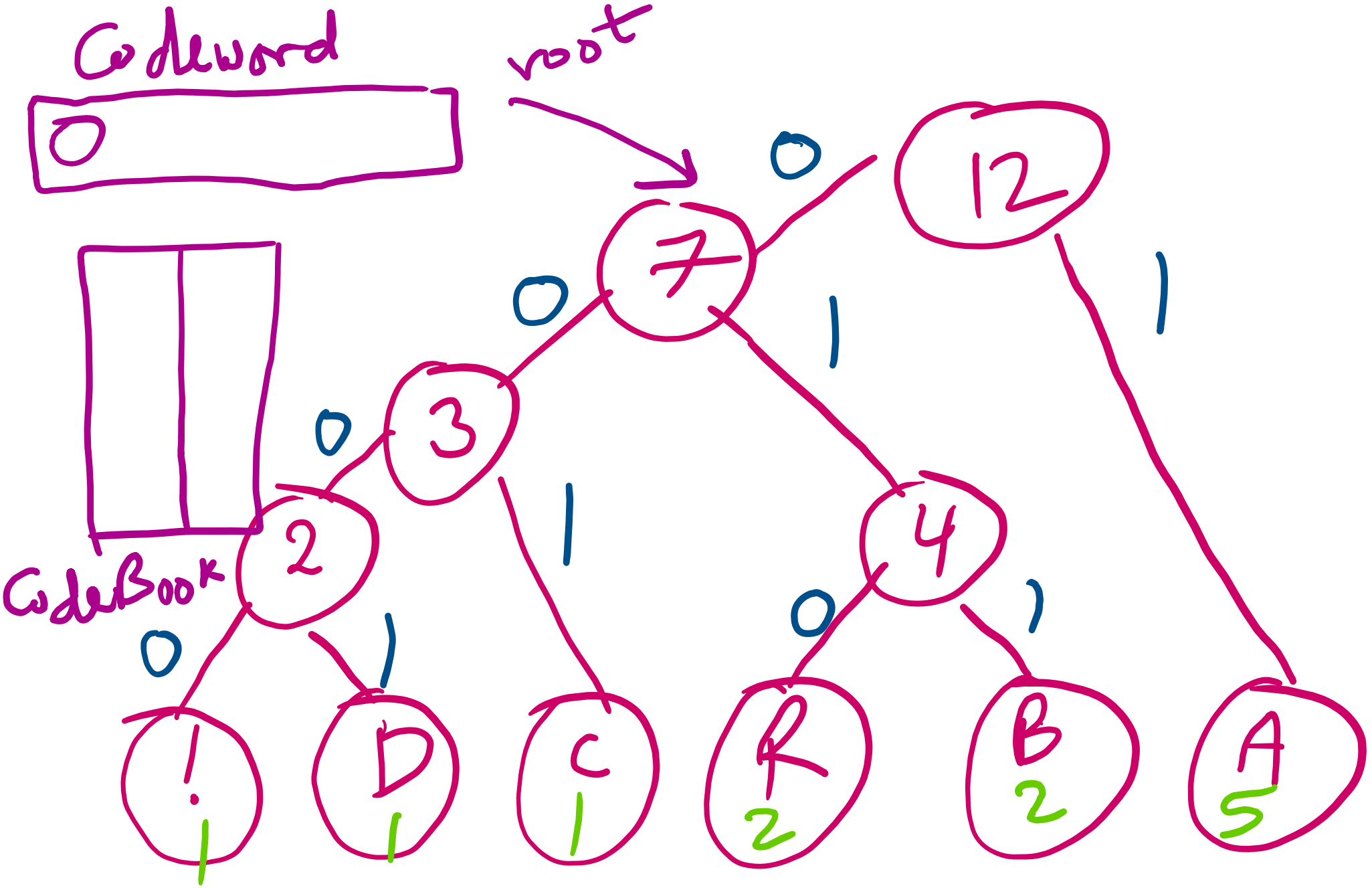
Huffman Compression: Generating the *Codebook*



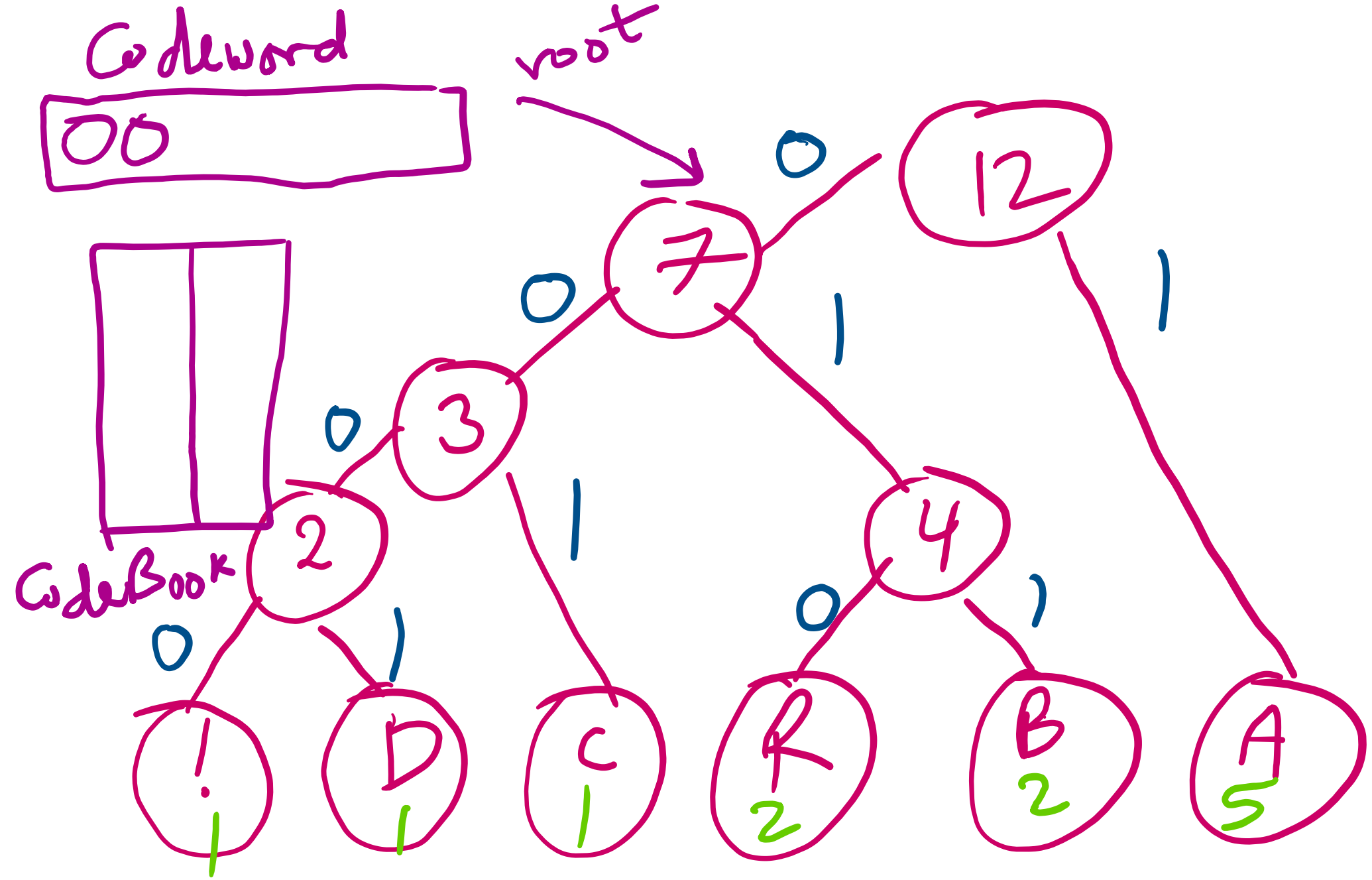
Huffman Compression: Generating the *Codebook*



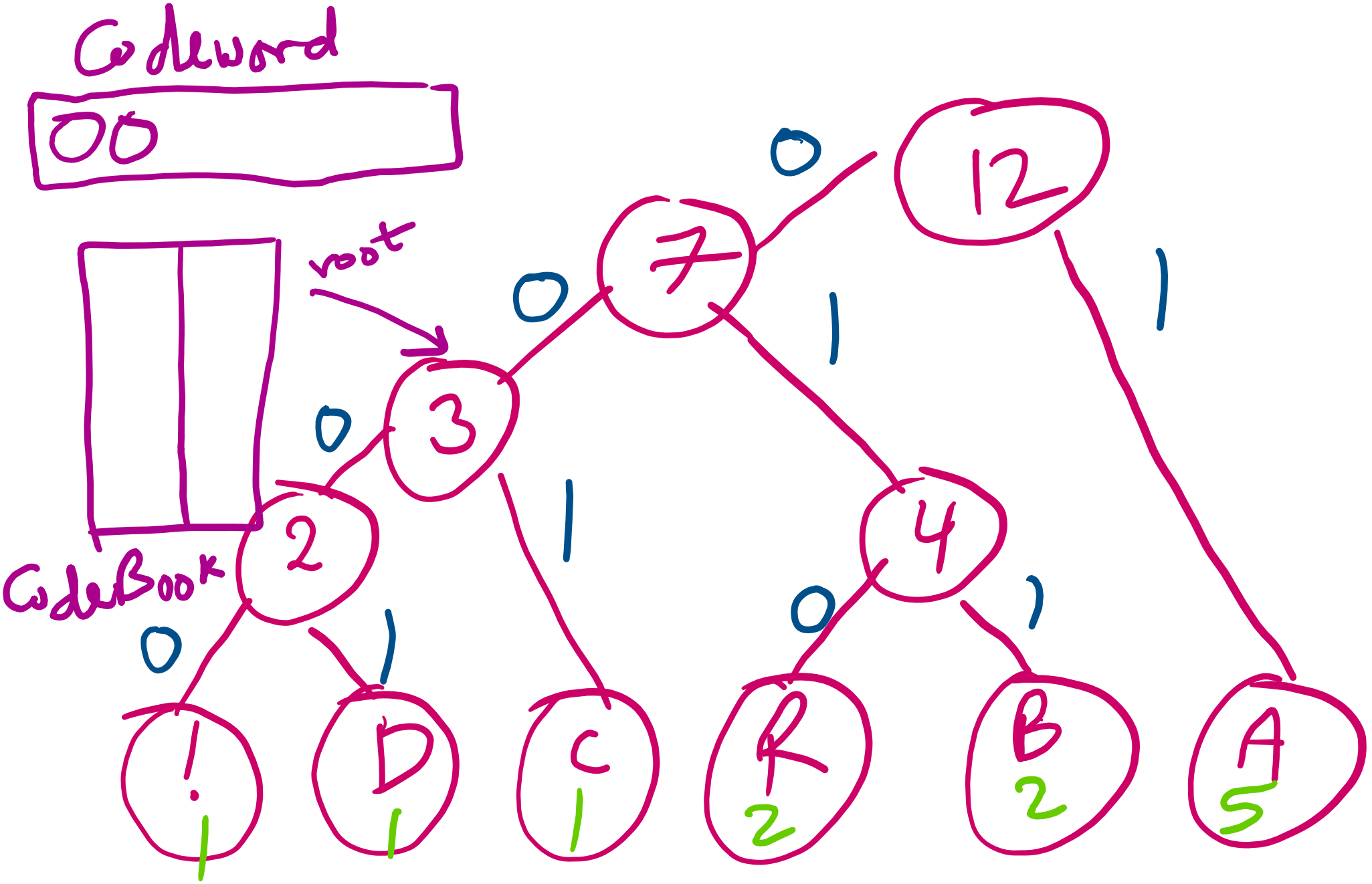
Huffman Compression: Generating the *Codebook*



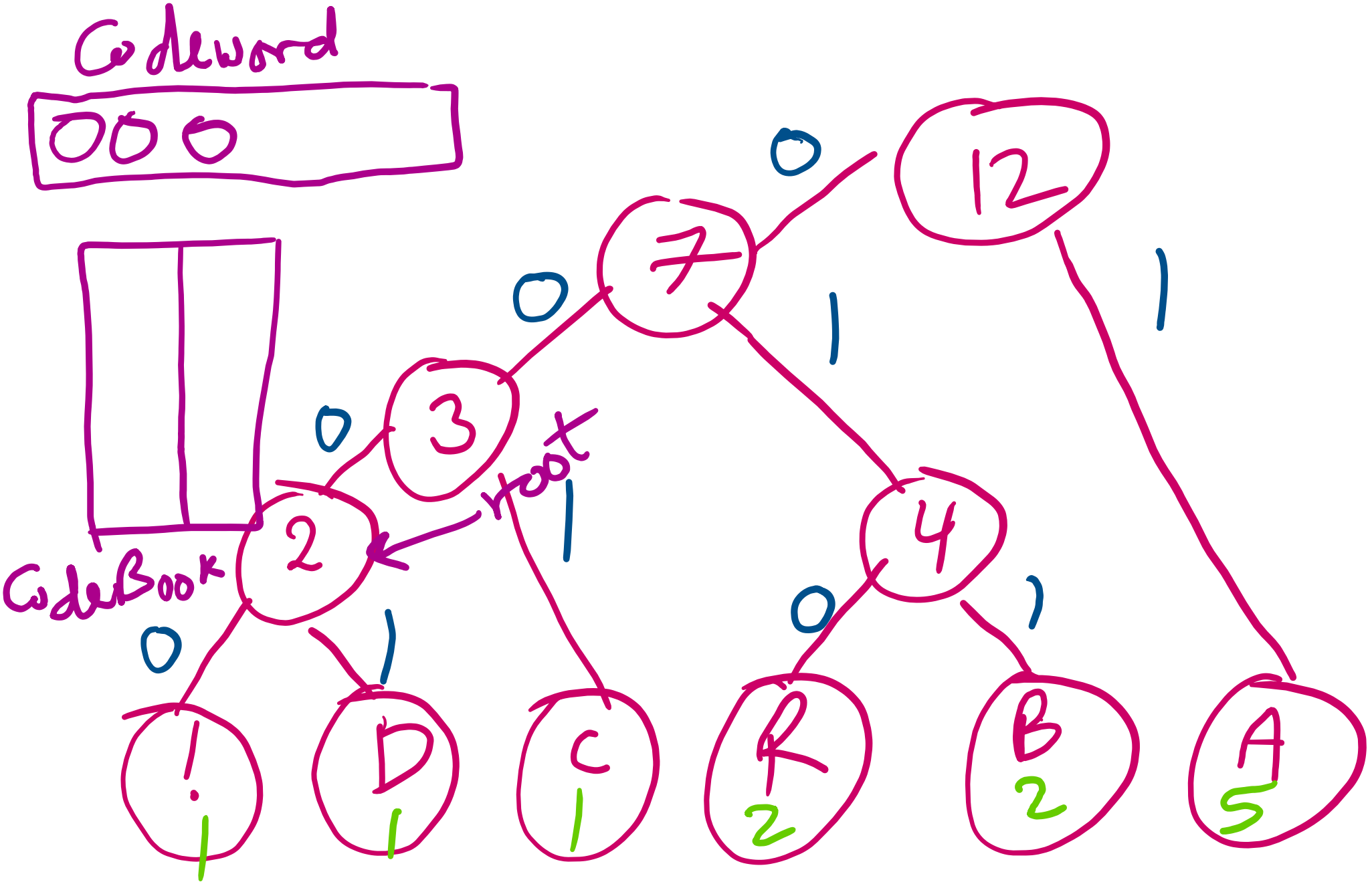
Huffman Compression: Generating the *Codebook*



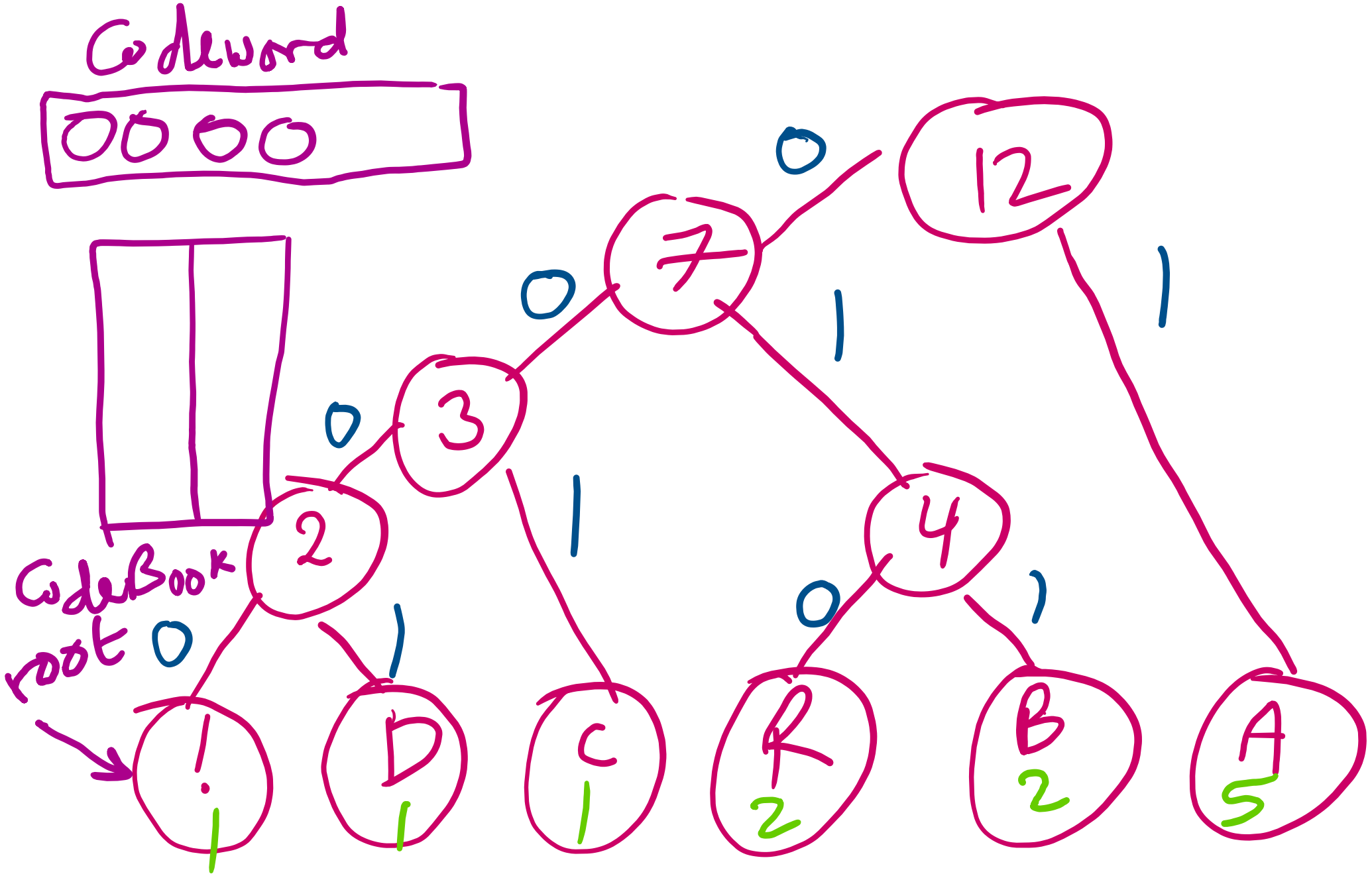
Huffman Compression: Generating the *Codebook*



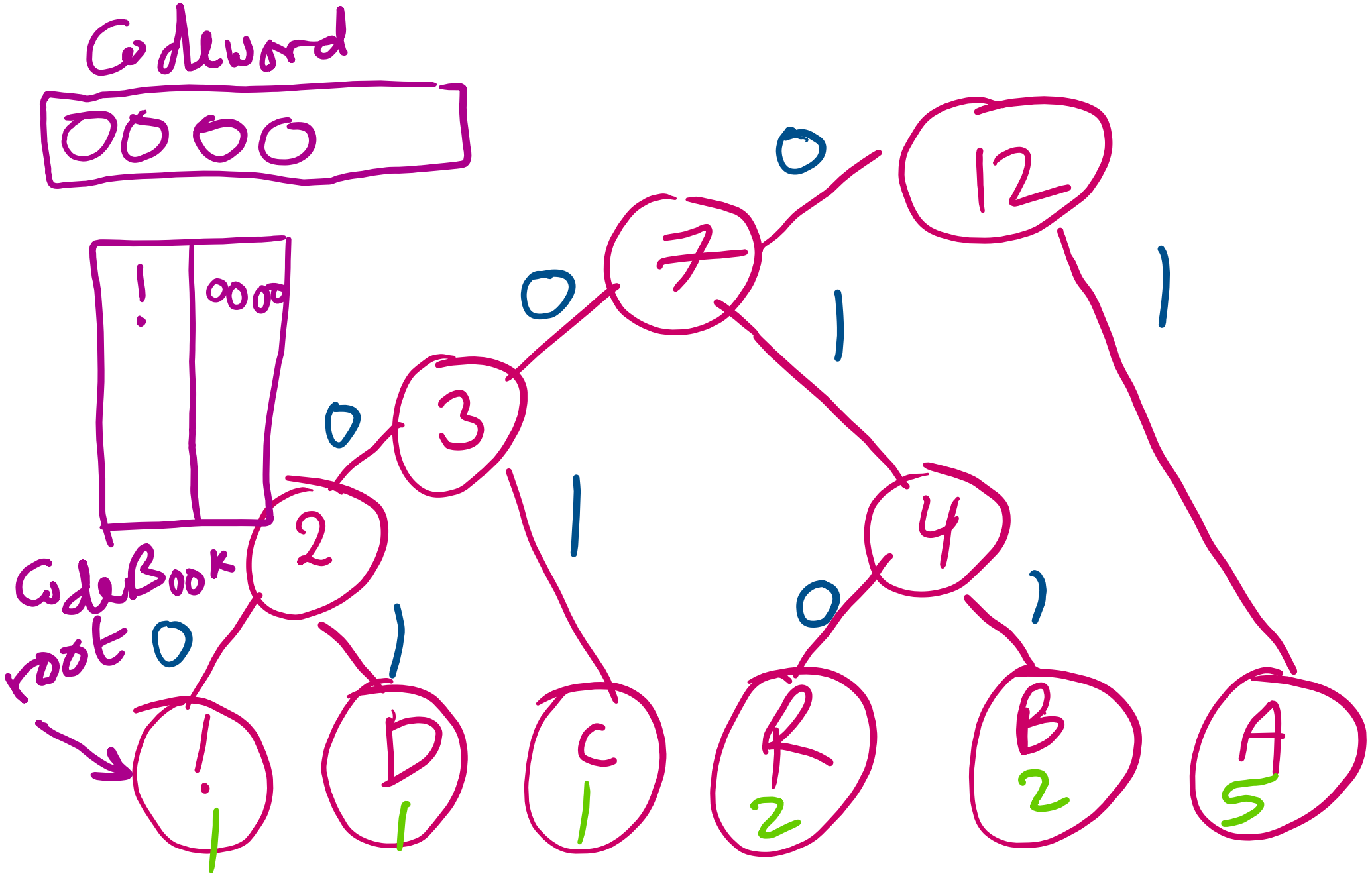
Huffman Compression: Generating the *Codebook*



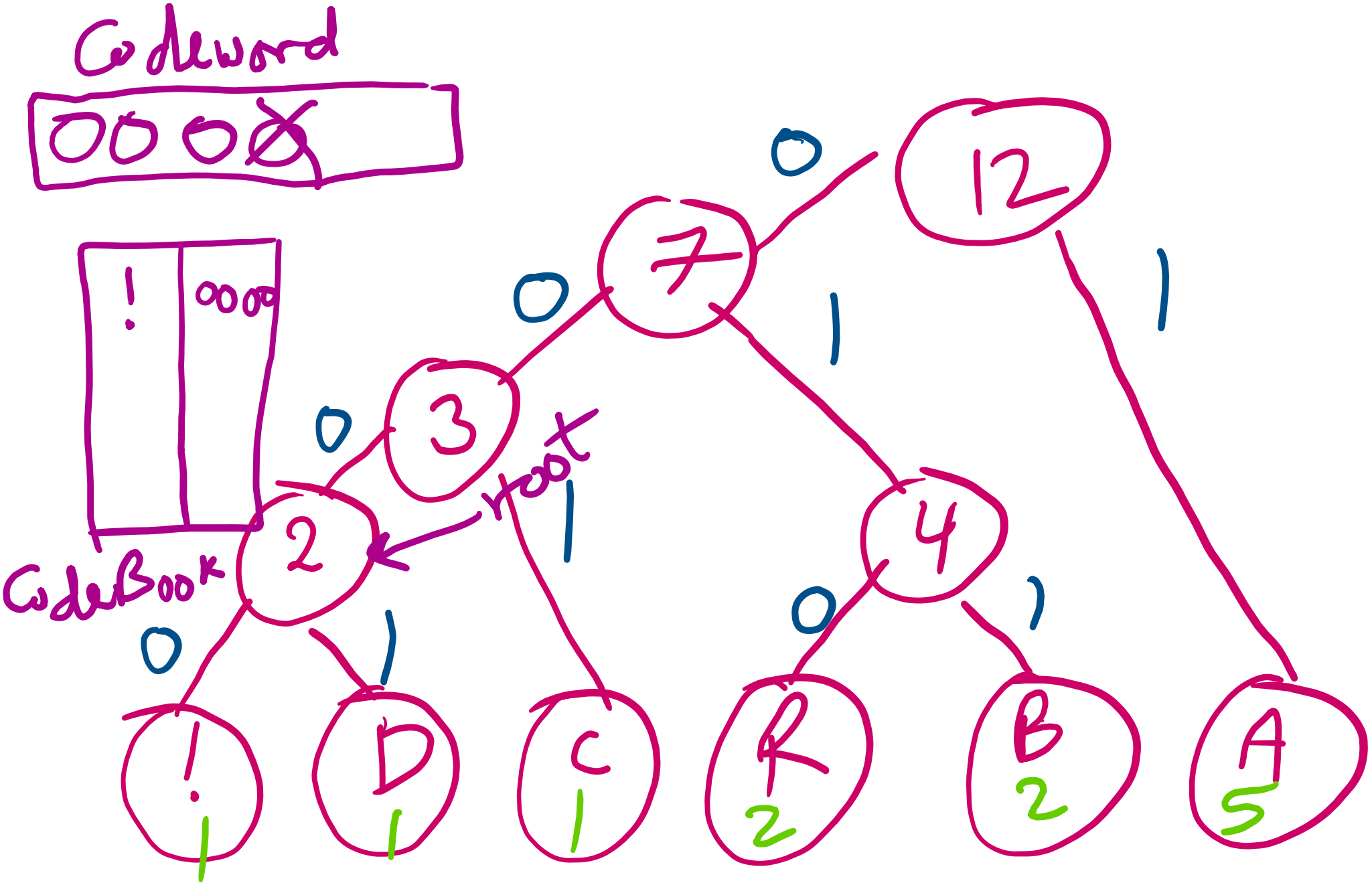
Huffman Compression: Generating the *Codebook*



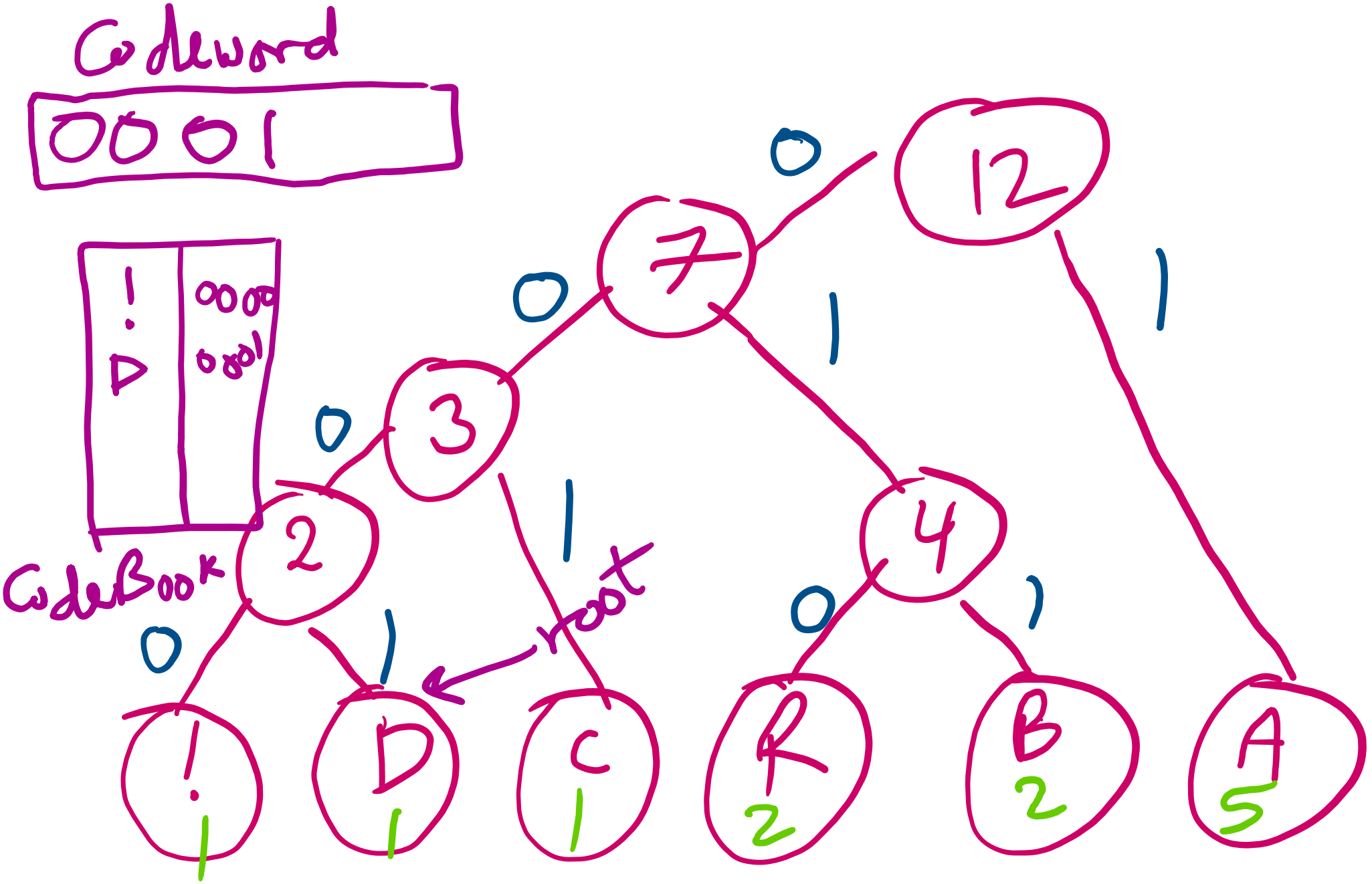
Huffman Compression: Generating the *Codebook*



Huffman Compression: Generating the *Codebook*



Huffman Compression: Generating the *Codebook*



Huffman Compression: Generating the *Codebook*

```
void generateCodeBook(Node root, StringBuilder codeword) {
    if(root.isLeaf()){
        codebook[root.data] = codeword.toString();
    }
    if(root.left != null){
        //append 0 to codeword, move left, pop last character in codeword
    }
    if(root.right != null){
        //append 1 to codeword, move right, pop last character in codeword
    }
}
```